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ORIGINAL ARTICLES.

I.—Studies in Edrioasteroidea. VI. *Pyrgocystis* n.g.

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(Concluded from the January Number, p. 12.)

C. *Pyrgocystis ansticei* n.sp. and others. (Plate III, Figs. 3–15.)

Previous History.—In 1892 Professor Carl W. S. Aurivillius published his well-known paper "Ueber einige ober-silurische Cirripeden aus Gotland" (Bihang Svenska Vet.-Akad. Handl. Bd. 18, Afd. IV, No. 3). Besides the remarkable specimen from the Ludlovian *Pterygotus* bed of Wisby, to which he gave the name *Pollicipes signatus*, and a supposed fragment of a scutum, which he called *P. validus*, Professor Aurivillius described a number of "kurze, mehr oder weniger cylindrische, mit Schuppen bedeckte Bildungen", which he regarded as the peduncles of a cirripede and referred provisionally, in the absence of any trace of a capitulum, to *Scalpellum*. Though all the specimens (except possibly of *S. cylindricum*) came from a single stratum, bed *c* of Lindström, probably contemporaneous with our Wenlock Shale, and though the majority were found in a single locality, Djupvik in Ekska, still Professor Aurivillius considered that he could with certainty distinguish the following seven species:—

S. sulcatum,	p. 13, fig. 11,	Bed *c*,	Djupvik,	abundant.
S. varium,	p. 15, figs. 12–14,	,,	,,	1 specimen.
S. granulatum,	p. 16, figs. 20–22,	,,	,,	3 ,,
S. ,, ?	p. 17,	,,	Wisby,	some ,,
S. strobiloides,	p. 17, figs. 17–19,	,,	Mulde,	1 ,,
S. procerum,	p. 18, fig. 15,	,,	Wisby,	? ,,
S. ,,		,,	Djupvik,	? ,,
S. fragile,	p. 19, fig. 10,	,,	Djupvik, Wisby,	3 ,,
S. cylindricum,	p. 18, fig. 16,	(horizon not stated),	Wisby,	1 ,,

In 1906 Colonel [now] Sir J. Arthur Anstice, K.C.B., a son of the Mr. John Anstice of Madeley whose collection was mentioned by Murchison and Prestwich, presented to the British Museum various fossils from the Coalbrookdale district; and among them were 14 specimens of the same character as those described by Aurivillius, and like them coming from the Wenlock Shale. Consequently they were at first placed provisionally among the Cirripedia. When, however, Professor Moberg's recent memoir (1914) led us to look through our Palæozoic cirripedes, Mr. T. H. Withers directed my attention to these fossils. Immediately close examination under the lens revealed

at the broken edges of the plates the clean crystalline cleavage distinctive of calcite and of echinoderm stereom, but not found in fossil remains of Arthropoda. Their echinoderm nature once recognised, it is further clear that all these fossils represent the stems or turrets of species resembling those from Minnesota and Girvan so far as that portion of the anatomy is concerned, and probably resembling them in the structure of the oral face. It is interesting to note that among the Gotland fossils referred by Aurivillius to *Scalpellum sulcatum*, is one which Hisinger had previously figured as "Columnæ Crinoidis fragmentum" (1841, *Lethæa Suecica*, Supplementi Secundi Continuatio, pl. xli, fig. 6). This reference by Hisinger, which, bearing in mind the former extended connotation of the name Crinoidea, now proves perfectly correct, seems to have aroused no suspicions in the mind of Aurivillius. On the contrary, he was quite certain that these fossils represented the stems of some genus of Lepadidæ, and, despite the great extension of geological range involved and the absence of congeners earlier than Cretaceous, he scarcely hesitated to refer them to the characteristically recent genus *Scalpellum*.

Students of early Palæozoic fossils know how often it has proved difficult to decide whether isolated plates, or associated fragments, or even whole skeletons, belonged to the Echinoderma or to the Arthropoda; but the criterion of stereom-structure, when it can be applied, ought to prove decisive. Apart from that, in the present instance, Aurivillius himself notes that in the peduncles of Recent Cirripedia the scales are embedded in a thick [uncalcified] chitin, or are only fastened by the base. In other words, the peduncle-valves of the cirripedes are never so closely set or so deeply imbricate as are the plates in these Silurian fossils; and the consequence of this is that up to the present, as Mr. Withers assures me, only two specimens are known in which a scalpelliform peduncle has been preserved in the fossil state with its valves in place,[1] and not a single one has been found apart from its capitulum. What a contrast is provided by the fossils before us, of which over a score have been picked up on a single beach in Gotland and fourteen in one Shropshire lane!

But apart from these fairly obvious considerations, which would have made an ordinary palæontologist hesitate, the general shape of the individual plates might well have raised a doubt in the mind of so high an authority on the recent Crustacea as Professor Aurivillius. The peduncular valves of cirripedes always show growth-lines over the whole outer surface, and definite facets where they abut or overlap; they are clear-cut structures, and in *Scalpellum* at any rate the earlier the species the more characteristic is the shape of the plate. But the plates of these Wenlockian fossils show at the most some minute irregular granules or rugæ, and have no distinct ridges or facets; they are quite unlike any cirripede plates of either Silurian or Recent times.

[1] *Scillælepas carinata* (Phil.), Miocene, Sicily: Seguenza, 1876, Atti Accad. Pontaniana, vol. x, pl. viii, fig. 14; and *Pollicipes concinnus* Morris, Oxford Clay, England: Darwin, 1851, Pal. Soc. Monogr. Foss. Lepadidæ, p. 50, pl. iii, fig. 1.

Material.—The fourteen specimens presented to the British Museum by Sir Arthur Anstice are registered E 16233 to E 16246, but may for convenience of reference be denoted by the letters *a* to *n*. They are all turrets in various degrees of preservation. Specimen *c* [E 16235] is taken as holotype.

Horizon and Locality.—All are from the Wenlock Shale of Jig House Bank, or, in the local vernacular, "Jiggers Bank." This, says Sir A. Anstice *in litt.*, "is a road that runs from Coalbrookdale up the right hand side of a steep dingle called Lloyd Brook dingle (the main road from Coalbrookdale to Wellington runs up this hill) . . . the road runs up the side of a steep bank, and there is a place called the Loam or Lum hole in the lower part of the dingle."

Detailed Description.—These fossils closely resemble the "*Scalpellum sulcatum*" of Aurivillius, with whose description the following may be compared.

The Turret is slightly curved and increases gradually in diameter from below upwards, frequently expanding rather suddenly at its adoral end, where the plates appear more closely packed.

The plates are arranged in eight columns, which may (as in *c*, Pl. III, Fig. 4) be quite distinct with grooves between, but which may be partly merged so that it is hard to say whether the number is 7 or 8 (e.g. *a*, *b*, *f*, *k*; Pl. III, Fig. 3), or may be clearly not more than 7 (e.g. *d*, *e*; Pl. III, Fig. 5). The vertical seriation is most plain in the middle half of the turret; towards the adoral end there is nearly always an irregularity connected with the expansion of the turret, which is usually more on one side and affects the packing of the plates; towards the lower end, as the turret contracts, the columns inosculate and become reduced in number, so that there may be only 4 or 5 at the base, increasing to 7 or 8 above (e.g. *l*, *m*; Pl. III, Figs. 6, 10). When the irregularity of the upper expansion has come in before the increasing plates of the lower end have taken their positions in definite columns, then the arrangement appears quite irregular (e.g. *j*). In those regions of the turret, or in those individuals, in which the complete arrangement in eight distinct columns has not been attained, the inosculation of the plates frequently appears on the surface as a column of smaller plates between two columns of larger ones; one result is the absence of a groove between the columns and a more even rounding of the surface, as described by Aurivillius for his *S. varium* and *S. strobiloides*.

The shape of the visible portion of each plate varies with the extent to which it is exposed, and with the greater or less distinctness of the columns. The shape of the whole plate is given in Pl. III, Figs. 14, 15; and the only variation of this seems to be in the greater or less relative width, producing a more obtuse or more acute angle. The sides of the upper half of the plate form a somewhat parabolic curve, the whole of which may be exposed; but however little be exposed it can never be likened to the segment of a circle. In the lower half of the plate the sides become more straight and vertical, or even converge slightly. Of course it is only at the distal end of the turret that the plates are ever fully exposed, and it is probable that the

relative height is greater there. The measurements of such plates in millimetres are :—

	a	*c*	*e*	*j*
Height	2·9	1·8	2·75	2·7
Greatest width . . .	2·0	1·6	1·8	1·6
Depth of portion exposed .	·6	·4 or less	·5	·2 in column, 1·5 when alternating.

Thus the ratio of width to height varies from ·88 to ·59 in different individuals, when plates of the same character are compared.

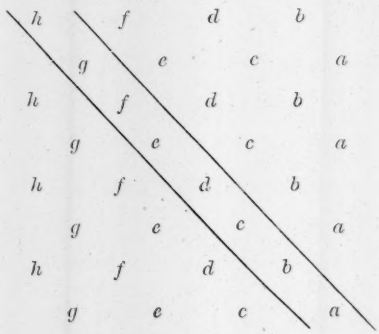
The number of plates in a column is 21 in *a* with a total height of 8·2 mm., 18 in *c* with a total height of 7 mm., about 16 in *e* where the portion preserved has a height of 5·6 mm., about 23 in *g*, with an approximate height of 8 mm. These numbers seem to imply that the plates are closer than in *S. sulcatum*, according to the measurement given by Aurivillius, who says 20 plates in 10 mm. But that measurement does not seem to take into account the more crowded plates at the two ends. His figure 11 suggests that there were in that specimen 27 plates in a height of about 10 mm. Probably there was no difference in this respect between individuals of the two species with clearly marked columns.

The amount of overlap is gauged by the proportion of depth of a plate exposed, and this in vertical series is somewhere about one-fifth. Aurivillius says of *S. sulcatum* "eine Schuppe nur die Hälfte oder oft nur $\frac{1}{3}$ der nächststehenden freilässt", but later on he gives the actual measurements for the middle region of the turret as ·5 in a length of 2·5 mm., i.e. one-fifth.

As regards the mutual relations of the plates in a tier, Aurivillius says: "Was die Anordnung in die Quere betrifft, stehen die Schuppen jeder zweiten Reihe auf derselben Höhe." If we letter the plates in a tier *a* to *h*, reading from right to left, then this sentence conveys the impression that the arrangement is as follows—

h *f* *d* *b*
g *e* *c* *a*

It will be observed that a repetition of this order in successive tiers would produce a line of the same letters ascending in spiral from right to left, *a* overlapping *b*, *b* overlapping *c*, and so on—



and a similar line descending from right to left, *b* overlapping *a*, and so on. This spiral arrangement is not conspicuous when the plates overlap closely, as in Aurivillius' fig. 11, and in those of our specimens that have clear vertical columns; but it is very plain when the overlap is less, though the alternation remains regular, as in Aurivillius' figs. 12, 15, 16, assigned by him to other species.

The slope of the plates towards the axis of the turret appears to be much as represented in Aurivillius' fig. 13, i.e. nearer the vertical below, and nearer the horizontal above.

In *c* the lumen at the lower end has diameters of 1·4 and 1·1 mm. The diameter of the turret at the top of the first tier of plates is 3·2 and 2·9 mm. (Pl. III, Fig. 8). This is the only specimen that shows a definite lumen at the distal end. In other cases the lumen is filled with plates (Pl. III, Fig. 7), or with plates and secondary calcite (Pl. III, Fig. 9), or it may be quite covered over with plates in a more horizontal position. Grinding down *n* at the distal end displays a section with diameters about 1·3 mm. and 2·9 mm. Aurivillius gives for *S. sulcatum* a lumen-diameter of barely 1 mm. and a turret-diameter [? same specimen and level] 3·5 mm. This indicates a relatively smaller lumen, but he says that the width increases towards the imagined capitulum. The section which he figures of *S. varium* (fig. 13) represents a different set of proportions; here the lumen does not increase upwards, but the contrary if anything, and at its lower end it is more than half the diameter of the turret, at its upper end a little less than one-third. In *S. strobiloides* the diameter of the lumen is said to be three times that of the wall; i.e. three-fifths the diameter of the turret. It is very doubtful whether the width of the lumen increased upwards in our Shropshire species; in the fossils at any rate it is filled with the more horizontally disposed and crowded plates, whose position cannot entirely be due to post-mortem shifting (Pl. III, Figs. 11, 12, 13).

The plates, when well preserved, are covered externally with fine anastomosing rugæ, showing a tendency to radiate towards the curved margins. Since these are developed equally on the exposed and unexposed portions of the plate, they must be regarded not as superficial ornament, but as an expression of stereom structure.

The plates are frequently broken on their free margins, so that either the tops are truncate or great pieces are, as it were, bitten out leaving jagged points conforming to the lines of crystalline cleavage (Pl. III, Fig. 3). This frequently gives the turret sides quite a peculiar appearance, as though they belonged to an entirely distinct species. The tops of the plates seem to be broken in the specimen of *S. strobiloides* shown in Aurivillius' fig. 17, which reminds one of the appearances in the Minnesota fossils.

There is no trace of any spines or spinules. But in *b* at the distal end, which is rounded, the ordinary large turret-plates seem to be covered by a number of very small plates the meaning of which is obscure.

Not a single specimen shows any trace of the oral face.

Measurements in millimetres are as follows:—

	a	*c*	*g*	*h*
Greatest length of turret	8·2	7	8·1	5·3
Diameter at adoral end .	4·0 × 4·4	4·9	5·1 × 5·7	2·2 × 3·5
Diameter at distal end .	ca. 3·0	3·2	ca. 3·6	1·5 × 2·8

Distinctions between the Wenlockian Species.—In spite of the variation as regards number and distinctness of vertical columns, there are good reasons for regarding all the Coalbrookdale specimens as belonging to a single species. First, the variations themselves merge into one another, and do so in such a way as to suggest that they represent stages of development, from fewer to more columns, and from alternation to seriation of plates. Secondly, there is little or no variation in the shape of the individual plates and in the nature of their ornament; and it is by characters such as these, little influenced by the cruder forces of the environment, that genetic differences are usually distinguished.

If now we apply the conclusions drawn from these Shropshire fossils to their contemporaries from Gotland, we find that the differences relied on by Aurivillius to distinguish his species are for the most part those which appear to us as simple growth-variations. So far as figures and descriptions allow one to judge, there seems no good reason why *S. sulcatum*, *S. varium*, and *S. fragile* should not all belong to a single species, for which the name *Pyrgocystis sulcata* would most naturally be adopted. *S. strobiloides*, represented only by the sole fragment found at Mulde, is probably no more than a slight variation, owing much of its different appearance to difference of preservation. *S. granulatum* seems to be distinguished by the nature of its ornament, but this again may only be due to better preservation; we have seen in *P. anstiei* that no weight can be attached to the difference in the direction of the plates at the distal end. Of the two long, cylindrical forms, *S. cylindricum*, known only from a single specimen, has plates of more pointed shape, and, since its horizon is possibly different, it may perhaps be left in its independence. The other, *S. procerum*, may also be distinct, but is more likely to consist merely of elongate individuals of *S. sulcatum*. It must be borne in mind that none of these specimens is really complete.

So much for the supposed differences between these Gotland forms. On the other hand, all, with the sole exception of the unique *S. cylindricum*, have plates of the same shape, namely, with the visible portion forming, in the words of Aurivillius, a segment of a circle. This fact, while confirming the view that they represent but a single species, sufficiently distinguishes them from the Shropshire specimens, in which the outline is consistently parabolic.

In the absence of any evidence to the contrary, such as might conceivably have been furnished by the oral face, these Wenlockian species must be referred to the genus *Pyrgocystis*.

The Relationships of Pyrgocystis.—It is clear that *Pyrgocystis* is an Edrioasteroid, but it is not clear whether it is to be referred to the Agelacrinidæ or the Edrioasteridæ. We need not consider either the Cyathocystidæ or the Steganoblastidæ in this connection.

According to the definitions given by me in 1899 and 1900 ("Treatise on Zoology," pp. 207–208), it would go more readily with the Agelacrinidæ; but in those definitions the differences in the subvective skeleton were not sufficiently taken into account.

In Studies I, II, IV, and V, the subvective skeleton of four Edrioasterid genera has been described in detail, and shown to consist of floor-plates and cover-plates, both disposed in alternating series, with pores between the floor-plates.

The evidence adduced by C. F. Roemer (1851), F. B. Meek (1873), Miller & Faber (1892), O. Jaekel (1899), J. M. Clarke (1901), and W. K. Spencer (1904) proves that in *Agelacrinus* (sensu lato) and *Hemicystis* among Agelacrinidæ, the subvective skeleton likewise consists of floor-plates and cover-plates, but that the floor-plates form a single series stretching right across the groove, and show no trace of pores. There is also a difference in the cover-plates, for normally in these two genera, as also in *Cystaster* and *Streptaster*, they are boot-shaped, with the sole of the boot adoral (= proximal) and the toe of the boot admedian, and in consequence of this shape they cannot close in the groove so completely as do the symmetrical cover-plates of the Edrioasteridæ. In some species of *Agelacrinus*, as shown in J. Hall's well-known figure of *A. cincinnatiensis* (1871), there are small additional cover-plates along the median line, much as may occur exceptionally in *Edrioaster* (Study IV, text-fig. 2). These additional plates, however, involve no departure from the essential plan of either group.

These two plans do not, I believe, exhaust the actual constructions employed in the Edrioasteroidea. Setting aside *Cyathocystis* and *Stromatocystis*, in which the structure is still not fully known, we may note *Lebetodiscus* (Study III), in which the cover-plates appear to be minute and to lie over the sutures between the floor-plates. The specimen figured by Jaekel (1899, *Stammesges. d. Pelmatoz.*, pl. ii, fig. 2) as *Agelacrinus Dicksoni* Billings, presents notches along the sides of its supposed cover-plates, and in other specimens I have observed these notches to be very distinct and regular: so that in such forms, it has seemed to me, there may have been minute cover-plates resting in the notches, and the larger visible plates may really be floor-plates.

The specimens of *Pyrgocystis*, so far as one can judge from the obscure evidence, do not display either cover-plates or floor-plates of the typical Edrioasterid or Agelacrinid plan. It is, however, conceivable that the plates observed correspond to the notched plates of the third plan of structure. Appearances that may possibly represent notches have been mentioned in the description of *P. grayæ*, and indications that the plates may perhaps not be cover-plates have been given in the description of *P. sardesoni*.

Those species which seem to me to have this supposed third plan of subvective structure, appear in all other points more closely allied to the Agelacrinidæ than to the Edrioasteridæ. In those same points it is with the Agelacrinidæ that *Pyrgocystis* also agrees. Therefore this genus may for the present be left in that Family. Although *Steganoblastus* is the genus of Edrioasteroidea that has the

most pronounced stem, and that manifests in its thecal structure the most pronounced reaction to such a mode of fixation, still it differs greatly from *Pyrgocystis* in the crinoid-like nature of that stem, in the solidity of the theca, and in the Edrioasterid character of the subvective skeleton. *Cyathocystis* again, especially in its more elongate individuals, presents a subvective system of straight grooves mounted on a turret of much the same proportions as in *P. sardesoni*. But the turret in *Cyathocystis* is a solid tube, and the structure of the whole oral face is totally different.

Among the Agelacrinidæ are some genera that approach *Pyrgocystis*. *Cystaster granulatus* as defined by J. Hall (October, 1871), from which Jaekel has attempted to separate some specimens as *Thecocystis sacculus* (1899), has straight rays surmounting an elevated sac-like body composed of minute plates or granules. In *Hemicystis* also the rays are straight, and Hall (October, 1871) specially mentions that *H. parasitica* and *H. stellata* have "the sides more abruptly elevated than the ordinary forms of *Agelacrinus*". The theca in *Hemicystis* is composed of minute squamiform plates. *Agelacrinus pileus* is said by Hall to have a "globular bell-shaped" theca when well preserved, and he figures a specimen in which many of the interradial plates "have a rounded node near the centre", possibly a spiniferous tubercle. In this species, as in all "*Agelacrinus*", the rays are curved.

The occurrence of spines in Pelmatozoa was probably more common than is generally supposed, but their preservation is certainly rare. Had specimen *a* of *P. sardesoni* not been found, nobody would have supposed that any species of *Pyrgocystis* bore spines; and the fact that they are not known in the other species is no proof that they were not present. No stress should be laid on the appearance of vertical rods on the cup-plates of *P. grayæ*, since they may be merely strengthening ridges. Meek (1873, Rep. Geol. Surv. Ohio, vol. i, pt. 2, p. 56) mentions ridges on the inner surface of marginal plates in an *Agelacrinus cincinnatiensis* (?).

Bionomics of Pyrgocystis.—The three formations from which specimens of this genus are known are of different lithological character.

P. sardesoni is found in a thin-bedded limestone, intercalated in soft green shales, and composed of numerous small fossils and fragments, but mainly of bryozoan skeletons, especially of branching bifoliate forms. This seems to suggest pure, relatively shallow water, crowded with animal life. The skeletons afforded a firm base of attachment for the Edrioasteroid's turret, which was under no necessity to be lofty since there was abundance of food and of aërating currents. There is no indication that the turret was fixed in other than a vertical position. The spines might conceivably be ascribed to some innate acanthogenous agency, or (less mystically) to an excess of lime in the water; but, whatever the contributory causes, we may suppose that the longer spines on the oral face were useful as a defence against worms and other predatory foes, while the spinules on the turret may have protected the soft stroma from parasitic organisms.

P. grayæ is preserved in a sandstone from which, as generally found, the calcareous constituents have been leached. This also was

a shallow-water formation, but not so rich in life as the Stictoporella bed, and especially poor in sedentary organisms. No firm base was afforded for the turret, which therefore seems to have tapered off to a pointed end thrust in the soft sand, while upwards it grew out of the reach of a bombardment by sand-grains (cf. "Caradocian Cystidea from Girvan", § 558). By the domed elevation of the oral face, the accumulation of sand-grains over the subvective system was prevented. The water was not so rich in lime, and parasitic enemies were not so numerous, wherefore it is probable that the reason why spines have not been preserved is because they never were developed in this species.

The Wenlock Shale of Shropshire, like the contemporaneous Bed *e* in Gotland, is a very fine-grained shale, apparently deposited in calm waters, in which lived a fairly numerous but rather dwarfed fauna, rich in ostracods and in small brachiopods and trilobites. There was no good fixation for the turrets, which seem therefore to have been rounded off at the distal end, and presumably stuck in the ooze, but may possibly have been attached to seaweeds. Frequently, it seems, they did not stand upright, and therefore grew in a slight curve. As a rule, relative want of lime made their plates thin and of a loose texture as now manifested in their dark colour. This also did not encourage the production of spines, which probably were absent. The differences between the various Wenlockian species do not seem to be of much physiological importance.

The results of the present Study may now be summarised in the following *Diagnoses.*

PYRGOCYSTIS[1] n.g.

An Agelacrinid with a subvective system of five broad straight rays mounted on a subcylindrical turret of adorally imbricate thin wide plates, which are not markedly different from those of the interradial areas of the oral face.

Range.—Lower Ordovician to Middle Silurian.

Genotype.—*P. sardesoni.*

P. SARDESONI n.sp.

A *Pyrgocystis* with diameter of turret equal all the way up, and about two-thirds its height, which is about 14 mm.; turret-plates in about 48 tiers of 11 plates in each, irregularly alternating and nowhere forming the complete 22 columns; each plate is from two to three times as wide as high, and is shaped like a segment of a flat ring. Not more than one-third of each plate is exposed. At the distal end of the turret the plates are almost horizontal; towards the proximal end they gradually approach the vertical, and finally merge into the interradial plates of the oral face, which is approximately horizontal. Spines are borne by all plates, those on the turret-plates being minute and not readily preserved.

Holotype.—Brit. Mus., Geol. Dept., E 16232.

[1] *πύργος*, a tower.

Horizon.—Stictoporella bed, Decorah shales, Lower Ordovician.
Locality.—St. Paul, Minnesota, U.S.A.

P. GRAYAE n.sp.

A *Pyrgocystis* with turret markedly tapering distalwards, its diameter in the proximal region about one-fifth its total height, which is about 20 mm.; turret-plates in about 80 tiers of about 5 plates in each, which in the proximal region alternate regularly so as to form about 10 columns; each plate appears to be probably wider than high, and to have an outer margin shaped like a flattened arc of a circle; the amount exposed is uncertain. The turret-plates seem to be laid at a steep pitch throughout; at the proximal end they form a distinct, almost vertical-walled, kind of cup, from which springs the high-domed oral face. Spines not observed.

Holotype.—Collection of Mrs. Robert Gray, Edinburgh, K 8.
Horizon.—Starfish bed, Drummuck series, Upper Ordovician.
Locality.—Thraive Glen, Girvan, Ayrshire, Scotland.

P. ANSTICEI n.sp.

A *Pyrgocystis* with turret slightly tapering distalwards, its diameter in the proximal region about one-half to two-thirds its total height, which is about 8 mm.; turret-plates in about 50 (or fewer) tiers of not more than 4 plates in each, which in the middle region alternate regularly, often forming 8 distinct columns separated by grooves; the width of each plate is from six-tenths to nine-tenths of its height; amount exposed about one-fifth, its margin a parabolic curve. The slope of the turret-plates in the fossils is nearer the vertical at the distal end, nearer the horizontal at the proximal end. Oral face and spines not observed.

Holotype.—Brit. Mus., Geol. Dept., E 16235.
Horizon.—Wenlock Shale, Middle Silurian.
Locality.—Jig House Bank near Coalbrookdale, Shropshire, England.

P. SULCATA Aurivillius sp.

Scalpellum sulcatum Auriv. 1892, p. 13.
Scalpellum varium Auriv. 1892, p. 15.
Scalpellum fragile Auriv. 1892, p. 19.
? *Scalpellum strobiloides* Auriv. 1892, p. 17.
? *Scalpellum granulatum* Auriv. 1892, p. 16.

A *Pyrgocystis* with turret slightly tapering distalwards, its diameter in the proximal region about half (or a little less) of its total height, which is about 11 mm.; turret-plates in about 50 (or fewer) tiers of not more than 4 plates in each, which alternate regularly, often forming 8 distinct columns, separated by grooves; the width of each plate appears [from Aurivillius' drawings; no measurements are given] to be greater than its height; amount exposed about one-fifth, its margin an arc of a circle. The slope of the turret-plates in the fossils is nearer the vertical towards the

distal end, nearer the horizontal at the proximal end, but they may be compressed and flattened at the extreme distal end. Oral face and spines not observed.

Holotype.—The original of Aurivillius' plate-fig. 11 is hereby selected. It is in the Riksmuseum, Stockholm. The holotype of *Scalpellum varium* is the unique original of Aurivillius' plate-fig. 12. The original of Aurivillius' plate-fig. 10 is hereby selected as holotype of *S. fragile*; it is not the specimen measured. The holotype of *S. strobiloides* is the unique original of Aurivillius' plate-fig. 17. The specimen measured by Aurivillius (p. 16) is hereby selected as holotype of *S. granulatum*; the figures may or may not be taken from this. All these specimens also are in the Riksmuseum, Stockholm.

Horizon.—Bed *c* (= Wenlock Shale), Middle Silurian.

Locality.—Djupvik in Eksta, also at Mulde and near Wisby, Gotland, Sweden.

P. PROCERA Aurivillius sp.

Scalpellum procerum Auriv. 1892, p. 18.

A *Pyrgocystis* with turret almost cylindrical, its diameter in the proximal region about one-third of its total height, which is not less than 10 mm.; turret-plates in at least 25 tiers of 4 plates in each, which alternate regularly, forming 8 columns separated by faint grooves; the width of each plate appears to be greater than its height; amount exposed fully one-half, its margin an arc of a circle; each plate is slightly bent on its vertical axis. The slope of the turret-plates approaches the vertical in all the portion preserved. Oral face and spines not observed.

Holotype.—The original of Aurivillius' plate-fig. 15 is hereby selected; it appears to be the specimen measured (p. 18). It is in the Riksmuseum, Stockholm.

Horizon.—Bed *c* (= Wenlock Shale), Middle Silurian.

Locality.—Aurivillius gives *a*) near Wisby, *b*) Djupvik in Eksta. I do not know from which of these the holotype came.

P. CYLINDRICA Aurivillius sp.

Scalpellum cylindricum Auriv. 1892, p. 18.

A *Pyrgocystis* with turret almost cylindrical, its diameter not more than one-third of its total height, which is not less than 9 mm.; turret-plates in at least 12 tiers of 4 plates in each, which alternate regularly, forming 8 columns, which are not separated but closely inosculate; the width of each plate is very little (if at all) greater than its height; amount exposed about two-thirds, its margin a pointed arch. The slope of the turret-plates approaches the vertical in all the portion preserved. Oral face and spines not observed.

Holotype.—The unique original of Aurivillius' plate-fig. 16, in the Riksmuseum, Stockholm.

Horizon.—Silurian, precise bed unknown.

Locality.—Near Wisby, Gotland, Sweden.

EXPLANATION OF PLATE III.

Pyrgocystis grayae.

FIG. 1. The holotype seen in three-quarter view from above, so as to show the oral face.

,, 2. The holotype seen from the side.

Both these figures are photographs from a squeeze of the original. × 3 diam.

Pyrgocystis ansticei.

,, 3. Specimen *a*. Side view. Note the irregular shape of the plates, due to fracture.

,, 4. Specimen *c*. Holotype, side view. Note the regular plates arranged in columns.

,, 5. Specimen *e*. Side view. Note the slightly irregular columns, of which there are only 7.

,, 6. Specimen *l*. Side view. Note the small number of columns at the distal end, with new ones coming in above.

,, 7. Specimen *g*. View of distal end. Since the turret is much curved, its side is also visible, though out of focus. There is no trace of a lumen.

,, 8. Specimen *c*. Holotype, view of distal end. The turret is slightly curved. There is a small distinct lumen.

,, 9. Specimen *e*. View of distal end. The position of the lumen is filled with a solid mass of plates and secondary mineral matter.

,, 10. Specimen *m*. Side view. Note the irregularity of the columns near the tapering distal end.

,, 11. Specimen *a*. View of adoral end. Note the approach to horizontality of the plates, and how they stretch across the lumen.

,, 12. Specimen *c*. Holotype, view of adoral end, as in Fig. 11.

,, 13. Specimen *i*. View of adoral end. Traces of the lumen are seen filled with matrix.

All the preceding figures, 3–13, are from photographs, taken and worked up by the author. × 3 diam., the same scale as Aurivillius' figures.

,, 14. Specimen *c*. Holotype. A plate at the distal end. × 7·5 diam.

,, 15. Specimen *j*. A plate at the distal end. × 7·5 diam.

Unfortunately it has not proved possible to obtain for comparison similar drawings of the plates in the Swedish species.

II.—Radio-activity and the Earth's Thermal History.

By Arthur Holmes, A.R.C.S., D.I.C., B.Sc., F.G.S.

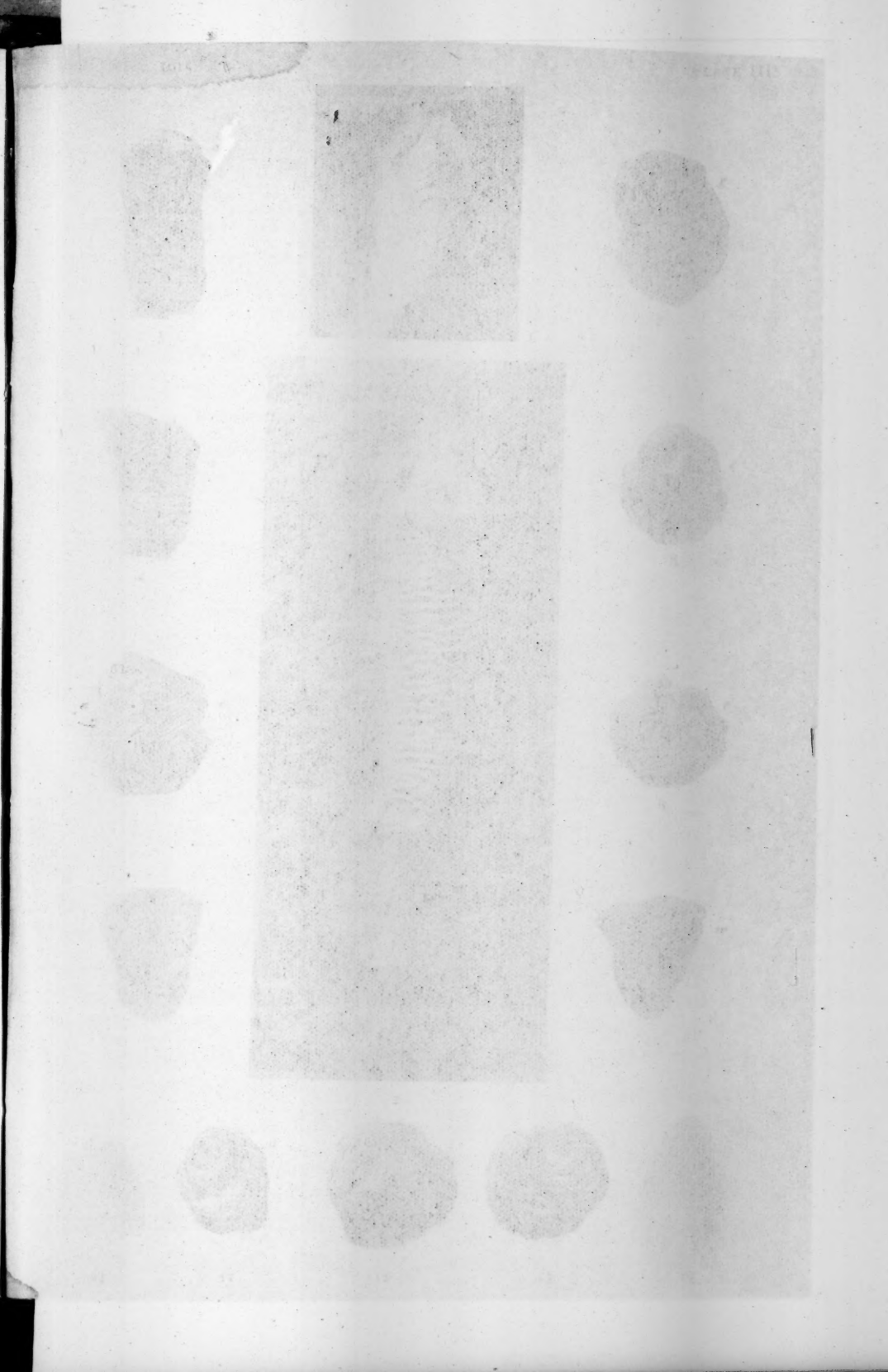
PART I.

The Concentration of the Radio-active Elements in the Earth's Crust.

1. Introduction.

TWO years ago, in discussing the thermal energy of the earth,[1] I suggested that while it had become impossible to deduce the earth's age from its thermal condition alone, Kelvin's problem might profitably be reversed by accepting the earth's age as a known factor, and deducing with its help the thermal history of the earth. This paper is a first attempt to attack the new problem then suggested. For geological purposes, one of the most fundamental aspects of the

[1] *The Age of the Earth*, p. 135, 1913.



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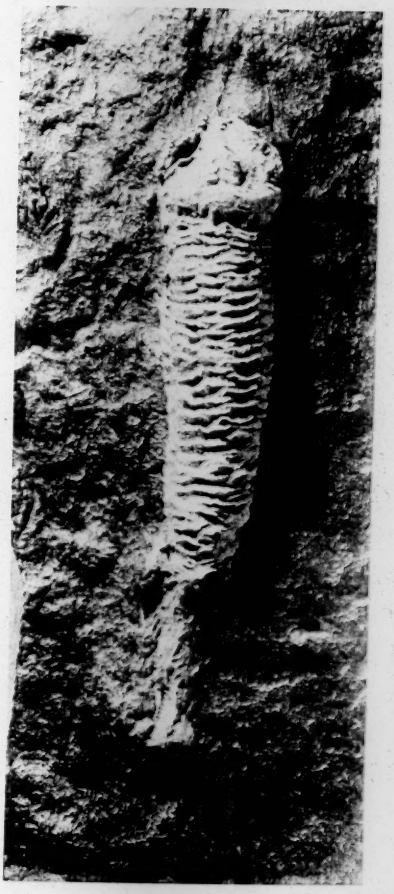

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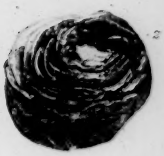

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problem is that relating to the depth within the earth's crust at which temperatures are attained such that, under suitable conditions of pressure, molten rock magmas may exist. The determination of the minimum depth of possible rock fusion is a first essential to any adequate theory of vulcanism, and indeed of igneous activity in general. It is not sufficient, however, to ascertain that depth for present conditions alone. Its variation during the earth's geological history must also be investigated; for if, as is generally believed, the earth is a cooling body, the depth must be slowly increasing, and in former periods it must necessarily have been nearer the surface than it is now. In the limiting conditions both of position and time, the depth of fusion may have been at, or so near as to be for all practical purposes at, the surface itself. That is to say, at the beginning of geological history the earth may have been in a molten condition at, or immediately below, the then existing surface.

The necessity of investigating this problem afresh arises from the discovery, within the last decade, of the widespread distribution of radio-active elements among the rocks of the earth's crust.[1] Although numerically the actual proportion of the radio-elements in the rocks is exceedingly small, yet owing to the fact that their disintegration is accompanied by a spontaneous generation of heat, it happens that their presence is fraught with a significance that cannot be over-emphasized. If each gram of the earth's substance were as rich in the radio-elements as are the rocks which have been examined, the earth's total output of heat from this source alone would, in any given period, be about 300 times as great as the amount actually lost by conduction to the surface and radiation into space.[2] If for 'gram' in the above statement, we substitute 'cubic centimetre', then the heat income would be more than fifty times the heat expenditure.

This astonishing result pulls us up sharply, for it is manifestly absurd to believe that our planet is becoming hotter at the appalling rate implied in these figures, or, indeed, that it is becoming hotter at all. There are two possible ways by which the dilemma may be avoided. The radio-active elements may be largely confined to the crustal rocks, leaving the main body of the interior free from the embarrassing results of their energetic decay; or, on the other hand, the disintegration to which the heat owes its origin may be inhibited under the conditions prevailing in the earth's interior. In the immediate problem before us, it matters little which of these views be accepted, for in each case the radio-active generation of heat is restricted to a superficial shell. It should, however, be pointed out that there is a strong consensus of experimental evidence pointing to an actual concentration of the radio-active elements in the earth's crust, whereas there is no evidence whatever that physical conditions can influence the rate of disintegration and heat production.[3] The experiments already made have reached temperatures up to 2500° C., and pressures

[1] Strutt, Proc. Roy. Soc., A, vol. lxxvii, p. 475, 1906; Holmes, *Science Progress*, No. 33, p. 15, 1914.

[2] Holmes, *Science Progress*, No. 33, p. 21, 1914.

[3] My *Science Progress* paper (No. 33, 1914) deals fully with this question.

up to 160 tons to the square inch,[1] which are quite sufficient for geological purposes, since they represent average conditions which cannot be generally reached at depths of less than 50 miles, or 80 kilometres, below the surface of the earth. To that depth, at least, the assumption of complete radio-active independence is thoroughly justified by direct experimental evidence. Since for thermal reasons the radio-active elements must be largely concentrated in an outer shell, it is of very little geological importance to decide the question of possible inhibition at depths greater than 50 miles.

2. Distribution of the Radio-active Elements.

As a result of a large number of experimental determinations of radium [2] in rocks and meteorites, first initiated by Strutt [3] and since continued by other workers,[4] it is now possible to state with confidence the salient features of the distribution of radium in rocks and meteorites of different types.

(1) Igneous rocks as a whole average more radium than sedimentary rocks.

(2) Metamorphic rocks agree in their averages with those of the igneous or sedimentary rocks from which they have been formed.

(3) The average for alkaline igneous rocks is higher than that for calc-alkaline rocks, and this important fact must be remembered in connexion with local exceptions to statement 5.

(4) The average for volcanic rocks is higher than that for plutonic rocks.[5]

(5) Acid igneous rocks average a higher content of radium than those of intermediate composition, and the latter, in turn, are richer than basic and ultra-basic rocks.

(6) The ultra-basic stony material of meteorites is poorer in radium than are terrestrial ultra-basic rocks.

(7) The metallic material of meteorites contains no radium, and in keeping with this significant fact terrestrial native iron is also free from radium.

Estimations of thorium have not been so numerous as those of radium, and most of the work has been done in the laboratories of

[1] Eve & Adams, *Nature*, p. 209, July, 1907.

[2] One part of radium in equilibrium with its parent uranium implies the presence of 3,000,000 parts of the latter element.

[3] Proc. Roy. Soc., A, vol. lxxvii, p. 472, 1906.

[4] See Joly, *Phil. Mag.*, vol. xxiv, p. 694, 1906 ; Holmes, loc. cit., p. 15, 1914, for references to literature.

[5] The unusually high radium content of recent Vesuvian lavas found by Joly is probably due to—

(1) Gravitational differentiation.

(2) Concentration by volatile fluxes.

(3) Association of radium, unaccompanied by its parent uranium, with potash minerals. It is well known that barium is commonly associated with magmas rich in potash, and it is therefore suggested that free radium may be similarly concentrated. In old lavas any such free radium would almost entirely have disintegrated, leaving to be measured only the radium which is directly related to the uranium present in the rock.

Professor Joly in Dublin, and Professor Mache in Vienna.[1] The results so far available serve to show that in the case of rocks the above statements serve equally well for thorium as for radium. Independently, this parallelism of distribution and mode of occurrence would be forcibly indicated by the common association of uranium- and thorium-bearing minerals with acid and alkaline rocks (e.g. granites and nepheline syenites), and in considerably greater quantities with their pegmatites. The most probable averages for common rocks and meteorites may be summarized as follows:—

TABLE I.

Type of Material.	Average per gram of rock.	
	Radium,[3] in grams $\times 10^{-12}$.	Thorium, in grams $\times 10^{-5}$.
Igneous Rocks.[2]		
Acid { volcanic	3·1	2·9
Acid { plutonic	2·7	
Intermediate { volcanic	2·1	1·7
Intermediate { plutonic	1·9	
Basic { volcanic	1·1	0·5
Basic { plutonic	0·9	
Ultra-basic	0·5	n.d.
Meteorites.		
Stone	0·25	n.d.
Iron-stone	0·10	n.d.
Iron	0·00	n.d.
Sedimentary Rocks.		
Argillaceous	1·5	1·1
Arenaceous	1·4	0·5
Calcareous	0·9	$<0·1$

3. The Density Stratification of the Earth.

The view that the earth is coarsely stratified according to the densities of its constituents is one suggested by—

(1) A comparison of the average density of crustal rocks with that of the earth as a whole.

(2) The structural characters of meteorites and the close correspondence in density and composition between their stony material and terrestrial ultra-basic rocks.[4]

(3) The structure of the earth's crust as indicated by the field relations and relative abundance of granite, basalt, and ultra-basic rocks.[5]

[1] Joly, *Phil. Mag.*, vol. xx, pp. 125 and 353, 1910, and Cong. Intern. de Radiologie et d'Electricité, p. 376, 1911; Fletcher, *Phil. Mag.*, vol. xx, pp. 102 and 770, 1910. See also Poole, *Phil. Mag.*, vol. xxix, 1915.

[2] Results for richly alkaline rocks, which are abnormally high in their radium and thorium contents, are omitted from this Table.

[3] Implying the series Uranium to Lead.

[4] Suess, *The Face of the Earth* (Eng. trans.), vol. iv, p. 544; Farrington, *Journ. Geol.*, vol. ix, p. 623, 1901; Merrill, *Am. J. Sci.*, vol. xxvii, p. 469, 1909; vol. xxxv, p. 509, 1913; Holmes, loc. cit., pp. 30–5, 1914.

[5] Von Cotta, *Geologische Fragen, Frieburg*, 1858, pp. 76–8; Green, *Vestiges of the Molten Globe*, pt. ii, p. 61, 1887; Daly, U.S.G.S. Bull. 209, p. 110, 1903; *Igneous Rocks and their Origin*, p. 162, 1914.

(4) The existence of surfaces of physical discontinuity within the earth as revealed by seismology.[1]

The broad conception of the structure of our planet which is suggested by these converging lines of evidence is that of a metallic core (average specific gravity = 7·8) occupying approximately half of the earth's total volume, surrounded by a thick peripheral shell (average specific gravity = 3·4) in which the silicate rocks are concentrated, becoming increasingly acid and alkaline as the crust (average specific gravity = 2·8) is reached. We are thus prepared for the conclusion that the radio-active elements are concentrated in the earth's outer shell, for the acid and alkaline rocks are just those which are richest in radium and thorium. It is an interesting fact that volcanic rocks, which are uniformly more acid and alkaline than their plutonic equivalents, are also richer in the radio-active elements. Rocks of gabbroid composition, which presumably underlie the immense granite and gneiss areas of the continents, contain less than a third as much radium and thorium as the granites. Ultra-basic rocks, which would seem to be comfortably at home only below the gabbroid zone, contain only a sixth as much. That the actual falling off in depth may be somewhat greater than these figures suggest, is indicated by the difference in radio-activity between volcanic and plutonic rocks. If the transfer of igneous magmas from levels corresponding to those at which we find stocks and batholiths, to those at which volcanic eruptions take place, is accompanied by so marked an increase in their content of the radio-elements, it seems probable that the whole upward journey may be marked by a progressive enrichment of a similar kind. Thus, even in rocks of the same composition, a decrease of radio-activity with depth is to be expected, but since the upward concentration must be mainly ascribed to gravitational differentiation,[2] and to the concentrating action of volatile fluxes, such an effect would certainly become less important as the depth increased.

So far, only the density stratification has been *assumed*, and the falling off of the radio-active elements in depth has been deduced as a natural consequence of that assumption. This was done to avoid any difficulty over the debated question of the inhibition of radio-activity by pressure. Conversely, if the independence of radio-activity be assumed, an assumption which, as I said before, is thoroughly justified, and indeed ceases to be an assumption, down to the limited depths with which petrologists are concerned, then the density stratification of the earth's crust follows as a natural consequence, as shown in the following discussion.

4. The Decrease of Radio-activity with Depth.

Since the view that the earth is getting hotter cannot be accepted, let us allow to radio active heating all that can be theoretically granted to it, and assume that the total amount of heat lost from the

[1] Milne, Proc. Roy. Soc., A, vol. lxxvii, p. 365, 1906; R. D. Oldham, Q.J.G.S., vol. lxii, p. 456, 1906; vol. lxiii, p. 344, 1907; *Nature*, August 21, p. 635, 1913.

[2] In spite of their very high atomic weights, the radio-elements tend to be carried upwards on account of their association with the lighter components of rock-magmas.

earth by conduction and radiation is exactly made good by radio-thermal action. Taking the simplest possible distribution of the radio-active elements, let us suppose that the average content of the surface rocks is uniformly maintained down to the maximum possible depth consistent with the limited heat production allowed to it. The depth of such a radio-active layer is easily calculated from the data now available.

The total amount of heat Q lost by the earth is given by the equation

$$Q = 4\pi r^2 . k . d\theta/dx \qquad (1)$$

in which $4\pi r^2$, the area of the earth's surface, is taken as 51×10^{17} sq. cm.; k,[1] the average conductivity of rocks, is taken as 0·006 for granite and gneiss, 0·005 for average igneous rock, and 0·004 for basaltic or gabbroid rock; and $d\theta/dx$, the average temperature gradient near the surface of the continents, is taken as 0·00032° C. per cm. or 1° C. in 31·25 metres. Since granite is by far the most abundant rock over the continents, the most accurate result is likely to be obtained by using the largest value given for k above.[2] For the sub-oceanic rocks the assumption is made that the heat lost per unit area is equal to the corresponding amount for continental rocks. Substituting the suggested values in equation 1, the total heat loss Q is found to be $9{\cdot}71 \times 10^{12}$ calories per second.

To determine the average amount of heat generated by the radio-active elements in each cubic centimetre of the crustal rocks, we must combine the average quantities of radium and thorium in the rocks with the respective amounts of heat produced by the two families of radio-active elements which are implied by the presence of radium and thorium. The latter factors are known with considerable accuracy.[3] Radium, implying the series Uranium to Lead (Radium G) in complete radio-active equilibrium, represents a generation of

[1] THERMAL CONDUCTIVITY OF ROCKS.

Igneous Rocks.				Sedimentary Rocks.	
Acid.		Basic.			
Felspar	0·0058	Basalt	0·00415	Marble	0·0050
Quartz	0·0095	Basalt	0·0052	Sandstone	0·0050
Granite	0·0081	Trap-rock	0·0038	Sandstone	0·0055
Gneiss	0·0058	Basalt	0·00352	Slate	0·0048
Granite	0·0060			Chalk	0·0025
Granite	0·0053			Clay-slate	0·0027
Porphyry	0·0084				
Trachyte	0·0059				
Syenite	0·0044				
Mean for rocks = 0·0063		Mean = 0·00417		Mean = 0·00425	

[2] If it is thought that this value of k (0·006) combined with a temperature gradient of 0·00032° C. per cm. gives an unfairly high result, it should be remembered (1) that the tendency in measuring temperature gradients is always to under- rather than over-estimate, and (2) that the heat lost from the earth by igneous activity is not included in the product $k . d\theta/dx$.

[3] See Rutherford, *Radio-active Substances and their Radiations*, pp. 583, 650, 1913.

6×10^2 calories per gram per second; thorium, implying the series Thorium to Thorium E in complete radio-active equilibrium, represents a generation of $7{\cdot}5 \times 10^9$ calories per gram per second.

Taking the average composition of the earth's crust [1] as equivalent to equal quantities of acid (granitic) and basic (basaltic or gabbroid) plutonic rock types, with specific gravities respectively of 2·66 and 2·95, we obtain the following results from the figures given in Table I.

TABLE II.

Type of Rock.	Acid.	Basic.	Average.
Specific gravity.	2·66	2·94	2·8
Radium in grams per c.c.	$7{\cdot}18 \times 10^{-12}$	$2{\cdot}65 \times 10^{-12}$	$4{\cdot}91 \times 10^{-12}$
Thorium in grams per c.c.	$7{\cdot}71 \times 10^{-5}$	$1{\cdot}47 \times 10^{-5}$	$4{\cdot}59 \times 10^{-5}$
Heat produced from radium in calories per second per c.c.	$43{\cdot}1 \times 10^{-14}$	$15{\cdot}9 \times 10^{-14}$	$29{\cdot}5 \times 10^{-14}$
Heat produced from thorium in calories per second per c.c.	$57{\cdot}8 \times 10^{-14}$	$11{\cdot}0 \times 10^{-14}$	$34{\cdot}4 \times 10^{-14}$
A = Total heat production per c.c. of rock in calories per second.	$100{\cdot}9 \times 10^{-14}$	$26{\cdot}9 \times 10^{-14}$	$63{\cdot}9 \times 10^{-14}$

The volume of rock required to maintain the earth in a state of thermal equilibrium is clearly given by Q/A, and the depth D of the layer in which the radio-activity is concentrated is given by

$$D = Q/4\pi r^2 \,.\, A \qquad (2)$$

Under the assumed conditions, the maximum temperature θ possible within the earth will be that at the bottom of the radio-active layer, and can be calculated from the expression [2]

$$\theta = AD^2/2k \qquad (3)$$

Since from equations 2 and 1

$$AD = Q/4\pi r^2 = kd\theta/dx$$

we may also write

$$\theta = \frac{k(d\theta/dx)^2}{2A} \qquad (4)$$

which gives the basal temperature in terms of known quantities without involving the composite factor D.

Substituting the values of A given in Table II we arrive at the following values of D and θ for the three types of rock material chosen for discussion:—

[1] Considered not only superficially but in depth also.
[2] Joly, *Radio-activity and Geology*, p. 272, 1909.

TABLE III.

Type of Rock.	Acid.	Basic.	Average.
k, thermal conductivity.	0·006	0·004	0·005
$d\theta/dx$, corresponding temperature gradient per cm.	0·00032° C.	0·00048° C.	0·00038° C.
D, depth of radio-active layer.	19 km.	70 km.	30 km.
θ, maximum temperature.	300° C.	1650° C.	570° C.

Of these results only that for basic rocks gives a temperature of the order required to explain the facts of vulcanism. The two others are manifestly absurd. Even if they be corrected to take into account the heat represented by the ascent of igneous materials through the crust (including the heat loss from volcanoes, fumaroles, solfataras, geysers, hot-springs, etc.) and a liberal allowance of 20 per cent of the earth's total loss of heat be assigned to this portion of it, the calculated temperature would still be far removed from the high values so forcibly demonstrated by vulcanism. The figures obtained for acid and basic rocks point to the way of reconciliation. Equation 4 indicates that A must decrease in depth if adequate temperatures are to be reached. That is to say, on the continents, where acid rocks predominate, the radio-activity of the rocks must decrease in depth; and a few trial calculations show that the decrease must be very rapid in order to allow the radio-active elements to persist to sufficient depths to give the requisite temperatures. This kind of decrease implies, as Table I clearly shows, a corresponding decrease in the acidity of the rocks and an increase in their density. The passage, at suitable depths, from granite to rocks of gabbroid composition would adequately accommodate the requirements.

Even in the case of average rock material the same argument holds. Under a continent of average composition the rocks in depth must soon give place to basic types. Briefly, the argument is that volcanic temperatures demand a rapid decrease of radio-activity with depth, and therefore a corresponding change in the composition of the igneous rocks which carry the radio-active elements.

The temperature arrived at for the basic rocks is satisfactory as it stands, but it has no meaning unless it be admitted—(1) that under the deeper and more permanent parts of the oceans the rocks are predominantly basic; (2) that the heat lost from the sub-oceanic rocks is about the same per unit area as that lost from the continents.

The first of these assumptions is supported by gravity measurements and the conception of isostasy, by the rocks themselves as exhibited in oceanic volcanic islands, and by the physical difference between sub-oceanic and sub-continental rocks which has been revealed by Oldham's interpretation of earthquake records. The second assumption is supported by the fact that the temperature gradients near the ocean borders are steeper than those well within the continents. The amount of heat issuing from the earth is proportional to the product of conductivity and gradient. Thus, if

the oceans lie in heavy basaltic depressions with a lower conductivity than the lighter granitic elevations of the continents, it follows that the gradients to be expected would be steeper for the former case than the latter, if the average loss of heat be everywhere approximately equal. Moreover, such a steepening can be explained at least partially as a result of the earth's superficial features. Near the surface the isogeotherms are approximately parallel to the surface; at greater depths they tend to become more and more nearly spherical and independent of superficial irregularities. Under the continents successive isogeotherms will therefore be more widely apart than their continuations under the oceans. That such a difference may actually exist is suggested by the fact that volcanoes are much more abundant well within the oceans than they are in the continental masses.

It would appear, then, that the two assumptions to which we are led are not without foundation, and for the present purpose they may be admitted without further discussion. It now becomes important to notice that if the continents are essentially granitic, with basic rock below, and the sub-oceanic rocks predominantly basic with little granitic covering and in some places even none, then the radio-active elements must be more abundant on and below the continents than below the oceans. Exactly how much so depends on the thickness of the granite covering in each case. If, to give an example, we assume that in the continents one-third of the total quantity of radio-elements in any vertical section is confined to the upper zone of granite and that the remaining two-thirds are distributed in basic rocks below, then it would appear that under the oceans a similar vertical section would provide only two-thirds of the total quantity of radio-elements found in a continental section. This would be a necessary consequence of any igneous mechanism by which granite was originally concentrated in the continental areas. In such a case the depth of the radio-active layer under the ocean would be about 47 km. instead of 70, and (from equation 3) the maximum temperature would then be reduced to 750° C. Thus the same difficulty arises as before, and we are led to the final conclusion that even on the extreme view here taken of the sub-oceanic rocks, their radio-activity must decrease with depth in order to provide sufficiently high temperatures. Here, however, the necessity for decrease is less severe, for a consideration of equation 4 shows that a temperature of 750° C. corresponds to a gradient just below the floor of the ocean, which is the same as assumed for the continents. If the actual gradient is steeper than this so as to bring up the heat output to the continental standard, then the additional gradient must be due to some source of heat more effective under the oceans than under the continents (e.g. igneous activity from below, compression, etc.), which in turn would provide higher temperatures in depth.

5. The Law of Decrease.

Case 1.—In the present state of our knowledge, it is, of course, impossible to state with mathematical precision the rate at which radio-activity decreases in depth. The continental case suggested above, in which one-third of the radio-activity is confined to a granite

shell (thickness 6·3 km.) and the remaining two-thirds to an underlying zone of basic rock (thickness 47 km.), would give a maximum temperature of nearly 1,000° C. This value is of the order required, and the conditions appear to agree fairly well with the probabilities of rock distribution.

The conditions, however, are not capable of being treated mathematically when stated in so crude a form. We require some law of decrease which can readily be stated mathematically so as to deal with the problem of a cooling earth as well as with volcanic temperatures. We have already seen that even in rock of uniform composition there is reason to believe that the radio-activity decreases with depth. Moreover, it is unlikely that the boundaries between successive zones of different density are as clearly cut as assumed in the above case. It is more probable that the lower portions of the acid shell are more basic than its upper parts, and similarly that the lower levels of the gabbroid sub-zone in turn approximate to the composition of the ultra-basic rocks beneath. It must be remembered that this variation of rock-types with depth refers to averages at each level and not to individual rock-masses. Igneous geology points to a natural antipathy between acid, basic, and ultra-basic types, so that it ought not to be assumed that there are levels at which intermediate types are characteristic, but only that the proportions of each main type vary at different depths. Combining the variation of rock-types with the suggested decrease of radio-activity in depth within any one rock-type, it would seem to be probable that the degree of heat generation decreases steadily from the surface downwards. The mathematical curve which can be made to agree most nearly with such a distribution is the exponential curve. We shall therefore assume an exponential decrease such that A_x, the heat generated per cubic centimetre at any depth x, is given by the equation—

$$A_x = Ae^{-ax} \qquad (5)$$

in which a is the percentage decrease in heat generation per unit distance. This law of decrease is such that if at a depth d the radio-active generation of heat per unit volume of rock has diminished to $A/2$, or half its surface value, then at a depth $2d$ the heat production will be reduced to $A/4$ or $A/2^2$, at a depth $3d$ to $A/8$ or $A/2^3$, and generally at a depth nd to $A/2^n$.

The value of a can be calculated from the total heat, q, which issues from each unit area of the earth per second.

$$q = \int_o^\infty Ae^{-ax}\,dx = A/a$$
$$= k\,d\theta/dx$$
$$\therefore \quad a = \frac{A}{k\,d\theta/dx} \qquad (6)$$

The half-value depth d is given by

$$1/a = 1{\cdot}443\,d \qquad (7)$$

The maximum temperature, θ, for the steady state is

$$\theta = A/a^2k \qquad (8)$$

and the temperature θ' at any depth x is

$$\theta' = A/a^2k\,(1-e^{-ax}). \qquad (9)$$

We may now proceed to apply these formulæ to different cases with the data already provided.

Case 2: Acid Rock.—Here $a = 5{\cdot}2 \times 10^{-7}$ and $\theta = 700°$ C. This certainly does not reproduce the actual conditions, for d, the half-value depth, is only reached at about 13 km., so that rock of basaltic composition would only be reached at a depth of 25 km. Again, the value of k adopted for acid rocks is too high to carry down to such depths, and the temperature obtained is insufficient.

Case 3: Basic Rock.— (*a*) Here $a = 2{\cdot}1 \times 10^{-7}$ and $\theta = 1580°$ C. if the temperature gradient 0·00032° C. per cm. be used in equation 6.

(*b*) If, however, we use the gradient appropriate to basic rocks, viz. 0·00048° C. per cm., then a becomes $1{\cdot}4 \times 10^{-7}$ and the maximum temperature is 3560° C.

(*c*) If now this result be applied to the sub-oceanic rocks it becomes necessary to make, as before, a correction for the smaller content of the radio-active elements under the oceans than that under the continents. Taking these contents respectively as 1 : 2/3, then the gradient due to radio-activity is only 0·00032° C. per cm., so that the temperature is just what we obtained at first, 1580° C. Any remaining part of the gradient would then, as already stated, be attributable to some other source of heat, which would correspondingly increase the temperature in depth.

Case 4: Average Rock.—(*a*) Here $a = 4{\cdot}0 \times 10^{-7}$ and $\theta = 800°$ C. when a temperature gradient of 0·00032° C. per cm. is used.

(*b*) Using the more appropriate gradient of 0·00038° C. per cm., the value of a is found to be $3{\cdot}4 \times 10^{-7}$ and θ becomes 1200° C.

The latter result is the most probable yet obtained and deserves further attention. The average radio-thermal conditions for the earth seem to lie between case 1 for the continents (temp. 1000° C.) and case 3 (*a*) or 3 (*c*) for the oceans (temp. 1580° C.). Case 4 (*b*) thus fairly represents the temperature requirements. At a depth of 50 km. the temperature would be 1100° C. (equation 9) according to the average conditions of case 4 (*b*). At the same depth the temperature under the oceans, case 3 (*c*), would be 1400° C., and under the continents, case 1, 900° C. Case 4 (*b*) may therefore be accepted as a fair representation of the earth's average conditions, stated in a way suitable for mathematical treatment. The data on which it is based are as follows:—

k, thermal conductivity . .	= 0·005 C.G.S. units.
$d\theta/dx$, temperature gradient .	= 0·00038° C. per cm.
A, total heat production per c.cm. at the surface .	= $26{\cdot}9 \times 10^{-14}$ calories per sec.

It must be carefully noticed that these data do not represent the facts at any actual place. They are simply an attempt to express the facts of rock distribution, both superficially and in depth, in a single average capable of being treated exponentially. I have tried various other more direct methods, but without success. The problems which await solution cannot be attacked except by an indirect method such as the above, which has the conspicuous advantage of giving results in harmony with volcanic phenomena.

6. Conclusions.

1. From the distribution of the radio-active elements among igneous rock-types and the variation of igneous rock-types in depth, it is deduced that the radio-active elements are specially concentrated in the earth's crust, the density of distribution being greatest near the surface, and falling off in depth.

2. Direct experiments show that radio-active disintegration, and therefore the consequent heat generation, are unaffected by temperatures of 2500° C. and by pressures of 160 tons to the square inch, conditions which correspond with those of a depth of 50 miles (80 km.) within the earth.

3. Thermal considerations demand, as an alternative to inhibition (which as shown in 2 cannot be assumed), that the radio-active elements should be almost altogether confined to an outer shell of the lithosphere.

4. Volcanic temperatures indicate that the density of distribution of the radio-active elements falls off rapidly with depth, the rate of decrease being perhaps greater under the continents than under the oceans.

5. For mathematical purposes radio-activity and heat generation are assumed to decrease exponentially in depth, this being a law of decrease which can be adapted to agree with the limiting conditions of rock distribution (superficially and in depth) and volcanic temperatures. The case chosen for further mathematical treatment is discussed in the preceding section, case 4 (*b*).

(Part II will appear in the March Number.)

III.—Brachiopod Morphology: Types of Folding in the Terebratulacea.

By J. Allan Thomson, M.A., D.Sc., F.G.S.

In descriptions of Recent and Tertiary Terebratulids at least, the type of folding is often hardly mentioned, and is left to be inferred from the figure, in spite of the fact that Douvillé[1] in 1879 showed that it might be even of generic importance. Buckman[2] has more recently drawn attention once more to the importance of this character and has shown that its due consideration may lead to fruitful results in classification. The object of this paper is to point out further cases in which it has been neglected.

Shells showing no folding, with a rounded anterior margin and a plane commissure, are said by Buckman to be in the 'lenticular stage'. Three primary modes of development of such a form are possible; it may become—

1. Dorsally uniplicate, i.e. with a single fold on the dorsal valve opposing a sinus in the ventral valve, or

[1] H. Douvillé, "Note sur quelques genres de Brachiopodes (Terebratulidæ et Waldheimiidæ)": Bull. Soc. géol. Fr., ser. III, tom. vii, pp. 251–77, 1879.

[2] S. S. Buckman, "Brachiopod Morphology: *Cincta*, *Eudesia*, and the Development of Ribs": Quart. Journ. Geol. Soc., vol. lxiii, pp. 338–43, 1907.

2. Ventrally uniplicate ('*Nucleatæ*' of Douvillé), i.e. with a single fold in the ventral valve opposing a sinus in the dorsal valve, or
3. It may pass to the *Cincta* stage, in which fold opposes fold and sinus opposes sinus.

By the development of a sinus in the middle of the single dorsal fold, the dorsally uniplicate forms may become dorsally biplicate, and by a similar process the ventrally uniplicate forms may become ventrally biplicate ('*Coarctatæ*' of Douvillé). Buckman has also shown how alternate multicarination and multicostation may arise from the dorsally uniplicate forms, and opposite multicarination from forms in the *Cincta* stage. It is hardly necessary to point out that a dorsally uniplicate form cannot become ventrally biplicate, or a ventrally uniplicate form become dorsally biplicate.

Douvillé recognized the above facts more or less clearly, and used them successfully to separate many forms from *Terebratula* and *Waldheimia*, but unfortunately in three cases (*Liothyris*, *Macandrevia*, and *Neothyris*) he was mistaken as to the type of folding actually exhibited by the shells. His mistake apparently arose from a belief that a straight front or an anterior truncation was necessarily due to a retardation of the *Cincta* type, for he placed these three genera among the '*Cinctæ*'. Now a straight front or an anterior truncation may be combined with dorsal uniplication, as is well shown, for example, in Kitchen's figures of Jurassic *Terebratulæ* from India.[1] It may equally well be combined with ventral uniplication. In cases where the plication is not of a pronounced type the only safe guide is the course of the anterior commissure. This is plane in shells in the lenticular or the *Cincta* stage, is arched upwards in shells showing dorsal uniplication, be it ever so slight, and is bent downwards in shells showing ventral uniplication. A slight tendency to uniplication can always be recognized by the arching up or bending downwards of the anterior commissure.[2]

Sub-family Terebratulinæ.

In *Liothyrina*[3] *vitrea*, the genotype, the anterior commissure describes a broad, rather flattened arch, and the type of folding is therefore incipiently dorsally uniplicate, and not of the *Cincta* type as supposed by Douvillé, and similarly all the recent species placed in that genus are either non-plicate in the lenticular stage, or are incipiently dorsally uniplicate. Buckman[4] considers that the chief characters of the genus (apart from its loop characters) are the possession of a thin test and of four internal radiating furrows which serve for the attachment of the pallial sinuses, characters seen in the Chalk species assigned to *Liothyrina*, viz. *Terebratula carnea*,

[1] *Palæontologica Indica*, ser. IX, vol. iii, pt. i, 1910.

[2] Apparently in certain species of *Terebratulina* a retardation of the *Cincta* type can set in after the shell has assumed an incipient dorsal uniplication.

[3] *Liothyris*, Douvillé, 1879, being preoccupied by *Liothyris*, Conrad, 1875, the name was changed to *Liothyrina* by Oehlert in 1887.

[4] "Antarctic Fossil Brachiopoda, etc.": Wissensch. Ergebnisse der Schwed. Südpolar Exped., 1901–3, Bd. iii, Lief. vii, pp. 26–7, 1910.

T. subrotunda, and *T. semiglobosa*. Now of these three species, according to Davidson's figures, *T. subrotunda* is non-plicate, *T. carnea* has incipient dorsal uniplication, while *T. semiglobosa* is incipiently biplicate. In *Liothyrina*, therefore, if we accept Buckman's view of the genus, the species form a series from non-plicate to dorsally biplicate.

Terebratula itself is a dorsally biplicate shell, the forerunners of which, in Buckman's [1] view, would be non-plicate, perhaps uniplicate, before becoming biplicate. We may go further and state that every Tertiary species with the *Terebratula* type of loop is either non-plicate, dorsally uniplicate, or dorsally biplicate. No ventrally uniplicate forms are known in the Tertiary of either hemisphere, although there is a Jurassic genus, *Glossothyris*, Douvillé, which has this type of folding. Where, then, are we to place the recent abyssal species *Terebratula wyvilli*, Davidson, subsequently assigned by Davidson to *Liothyris*, a shell showing pronounced ventral uniplication? Its type of folding excludes it at once from *Liothyrina* and *Terebratula*, and it can hardly be supposed that *Glossothyris* could retain its characters with such persistence through so many millions of years. It seems necessary to create a new genus for its reception, but I refrain from this step in the hope that some one who has access to specimens will compare its internal characters with those of *Glossothyris* and obtain evidence of another kind that will make the way clearer. It may further be suggested that the sub-family Terebratulinæ, in which Schuchert includes indiscriminately shells showing series from non-plicate to dorsally biplicate, to ventrally biplicate, and to extreme folding of the *Cincta* type, is unwieldy and in need of revision.[2]

Sub-family Magellaninæ.

Turning next to the Magellaninæ, we find a much greater uniformity in type of folding. Douvillé considered that *Magellania flavescens*, the genotype of *Magellania*, belonged to the '*Coarctatæ*', that is, that it possessed ventral biplication, while *M. lenticularis* belonged to the *Cinctæ*, and he therefore made the latter species the type of a new genus, *Neothyris*. In the case of *M. flavescens*, Buckman, apparently overlooking Douvillé's statement, declared that it showed a little indication of ventral uniplication. I think, however, that Douvillé was justified, for in many specimens the anterior commissure shows a dominant ventral uniplication on which is imposed the beginnings of biplication. In any case it cannot be doubted that many Australian Tertiary species assigned to *Magellania*, e.g. *M gambierensis* (Etheridge fil.),[3] possess distinct ventral biplication.

In the case of *M. lenticularis*, however, Douvillé was mistaken, for it is not in the *Cincta* stage, but, as its anterior commissure shows, is just passing out of the lenticular stage to incipient ventral

[1] "Brachiopod Nomenclature: the Genotype of *Terebratula*": Ann. Mag. Nat. Hist., ser. VII, vol. ix, pp. 525–31, 1907.

[2] See further remarks on this point under the Dallininæ.

[3] Ann. Mag. Nat. Hist., ser. IV, vol. xvii, p. 19, pl. ii, figs. 4*a–d*, 1876.

uniplication. In other words, *Neothyris* and *Magellania* belong to the same series of folding, viz. from non-plicate to ventrally biplicate, and on this ground, therefore, there is hardly reason for *Neothyris*, which, as a matter of fact, has been suppressed by most modern authors. Digressing from consideration of types of folding, I may point out that there are other grounds on which *Neothyris* may stand as a very good genus. *N. lenticularis* differs from *M. flavescens* in exactly the same way as *Pachymagas tehuelca*[1] differs from *Terebratella dorsata*, viz. in the possession of a bifurcating septum and extremely thickened socket-ridges and cardinal process, as against a simple septum, thin socket-ridges, a lamellar hinge-plate, and a small transverse cardinal process.

Every Recent and Tertiary species referable to *Bouchardia*, *Magasella*, *Pachymagas*, *Terebratella*, *Neothyris*, and *Magellania* belongs to the same series of folding, viz. from non-plicate to ventrally biplicate, and this may be taken as a character of the Magellaninæ.[2] Alternate multicostation arising directly from a smooth stage is found on some species of *Terebratella* and *Magellania*, but this is superposed on the ventral plication. Schuchert, however, includes in this sub-family the genera *Cœnothyris* and *Ismenia*, the former of which is distinctly dorsally uniplicate, while the latter possesses an alternate multicarination, which, as Buckman has shown, is probably derived from a dorsally uniplicate form. These two genera, therefore, should be removed from the Magellaninæ.

Sub-family Dallininæ.

Turning next to the Dallininæ, we find a much greater diversity. In *Dallina* itself, *D. septigera* (the genotype) is dorsally biplicate, *D. raphælis* is the same, while *D. floridana* is dorsally uniplicate, all belonging to the series lenticular to dorsally biplicate. *Terebratula grayi*, Davidson, which was also referred by Beecher to *Dallina*, is a ventrally uniplicate shell with alternate multicostation, and cannot therefore belong to *Dallina*. There seems to be no difficulty in referring it to *Magellania*, as it apparently possesses the Magellaniform hinge-plate and cardinal process. Now *Dallina* and its forerunners must all belong to the series non-plicate to dorsally biplicate, but for the immediate forerunner, *Terebratalia*, Beecher[3] has chosen for genotype *Terebratula transversa*, Sowerby, a shell which is undoubtedly ventrally uniplicate. This was the more unfortunate, as the actual species on which he established a different ontogenetic series from that of *Terebratella*, s.str., was *Terebratella obsoleta*, Dall, which is a dorsally uniplicate form. *Terebratula transversa*, Sow., and *Terebratula coreanica*, Adams & Reeve, two ventrally uniplicate forms from the North Pacific which have been referred to *Terebratalia*, are,

[1] H. von Ihering, Ann. Mus. Nac. Buenos Aires, tom. ii, p. 332, 1903.

[2] Apparent exceptions are the New Zealand Tertiary forms *Terebratula gaulteri*, Morris, and *Terebratella sinuata*, Hutton, which are dorsally uniplicate, but these have proved to be smooth Rhynchonellids.

[3] C. E. Beecher, "Revision of the Families of the loop-bearing Brachiopoda. The Development of *Terebratalia obsoleta*, Dall": Trans. Conn. Acad., vol. ix, pp. 376–99, pls. i and ii, 1893.

I believe, true *Terebratellæ*, and if this be so *Terebratalia* becomes a synonym of *Terebratella*. Before this position can be disputed it is necessary to study their young stages and show that they are not comparable to those of *Terebratella*.[1] Beecher was apparently misled by the general separation of the Dallininæ and the Magellaninæ in the northern and southern oceans. Jackson[2] has already shown that the Dallininæ have a species (*Macandrevia diamantina*) in Antarctic waters, and it now appears that the Magellaninae have at least three genera, *Magellania*, *Terebratella*, and *Magasella*, represented in the North Pacific.

But even if it should be shown that *Terebratalia* is distinct from *Terebratella*, there can be no question, on account of the difference in folding, that *Terebratella obsoleta* cannot be referred to *Terebratalia*, and a new genus is necessary for its reception, and this I now propose.

Dallinella, genus nov.

Genotype, *Terebratella obsoleta*, Dall.[3]

Shell non-plicate to dorsally uniplicate. Loop passing in growth through Platidiform, Ismeniform, and Muehlfeldtiform stages, attaining finally a stage resembling *Terebratella*. The non-plicate *Terebratula spitzbergenensis*, Dav., and the dorsally uniplicate *Terebratella Mariæ*, A. Adams, may apparently also be referred to *Dallinella*.

We have, therefore, in the Dallininæ a recent stock of shells, ranging from non-plicate to dorsally biplicate, represented by the genera *Dallina* and *Dallinella*. Amongst fossil stocks with the same types of folding may be mentioned *Kingena*, *Epicyrta*, *Cœnothyris*, *Plesiothyris*, and the multicostate genera *Ismenia*, *Eudesia*, and *Flabellothyris*.

But those are also genera which go through growth-stages similar to those of *Dallina* so far as loop-development is concerned, but are ventrally plicate. *Macandrevia* appears to be non-plicate in the genotype *M. cranium* and not in the *Cincta* stage as Douvillé thought, but *M. diamantina*, Dall, is clearly a ventrally uniplicate form. The Recent species of *Muehlfeldtia* are incipiently uniplicate, and *Platidia* also shows the beginnings of ventral uniplication. We should expect to find a genus of Recent or Tertiary shells in this series with Terebratelliform loop which might be regarded as the forerunner of *Macandrevia*. Possibly this lack is supplied in the species *Terebratula frontalis*, Middendorff, which agrees with expectations in being ventrally uniplicate, in possessing an incomplete foramen and a short median septum not reaching posteriorly to the umbo, but we are left in ignorance by Davidson as to the nature of the hinge-teeth and

[1] The hinge-plates of these species appear to be Terebratelliform, and Davidson has stated that the growth stages of *T. coreanica* resemble those of *T. rubicunda*. If *T. grayi* is correctly placed in *Magellania*, the presence of *Terebratellæ* in the Northern Pacific is only to be expected.

[2] J. W. Jackson, "The Brachiopoda of the Scottish National Antarctic Expedition": Trans. Roy. Soc. Edin., vol. xlviii, pp. 367–90, 1912.

[3] In case Beecher has made any mistake in his identification of this species, with which I am unacquainted, I further desire to define the genotype as the species actually figured by Beecher under the name of *T. obsoleta*, Dall.

whether dental plates are present or not. A peculiar feature in this species is the divided hinge-plate. It has points of resemblance to some Magaselloid stocks, but does not agree with any known to me. In any case this species cannot find a place in *Terebratella* or *Dallinella*. Among fossil genera referred to the Dallininæ which show ventral uniplication are *Aulacothyris*, *Trigonosemus*, *Orthotoma*, and *Camerothyris*, while *Antiptychina* is ventrally biplicate. It is open to question, however, whether these fossil genera really belong to the Dallininæ or to the Magellaninæ until the mode of development of their loop is known.

Finally, there are amongst Recent shells ascribed to the Dallininæ some which show anterior retardation of the *Cincta* type. Of these the best example is *Terebratula blanfordi*, Dunker, which was described and figured by Davidson as a *Terebratella*, but was later referred to *Laqueus* by Dall [1] on account of its loop characters. This species has a well-marked mesial sinus on each valve and an excavate front, and the same characters are possessed in a lesser degree by *Laqueus rubellus* (Sow.) and *L. jeffreysi* (Dall).[2] Of the remaining species ascribed to *Laqueus*, *L. pictus* is non-plicate and apparently in the lenticular stage, though there is a tendency towards a straight front, but *L. californicus*, which is the type of the genus, occupied an anomalous position, for according to Davidson's figures and descriptions it shows the beginnings of ventral uniplication. It appears as if in this case a stock in the lenticular stage were evolving in two directions, giving rise on the one hand to species with ventral uniplication and on the other to species with *Cincta* retardation. As the process has not gone very far, it seems hardly necessary to separate the *Cincta*-like forms under a new genus at present.

Among fossil genera ascribed to the Dallininæ which show anterior retardation of the *Cincta* type are *Cincta*, *Microthyris*, *Zeilleria*, *Trigonella*, and *Trigonellina*.

As in the case of the Terebratulinæ, then, we have in the Dallininæ genera belonging to each of the three series of folding. It is not suggested that *Laqueus blanfordi* is necessarily more nearly related to *Cincta* than to *Dallina* or *Macandrevia*. A great deal more must be learned before we are in a position to know the relationship of the various members of the Dallininæ to one another, and in this connexion a study of the beak characters, hinge-plate, and cardinal process may be of considerable service.[3]

The simplicity of types of folding in the Magellaninæ and the complexity in the Dallininæ at least suggest that these two subfamilies are not of equal taxonomic value.

[1] Proc. U.S. Nat. Mus., vol. xvii, pp. 724–6, 1895.

[2] Originally described by Dall as *Frenula jeffreysi*, and later by Davidson as *Laqueus californicus*, var. *vancouveriensis*. See Dall, loc. cit.

[3] These characters are proving of considerable aid in separating different stocks of the Magellaninæ among New Zealand Tertiary shells which have arrived independently at Magellaniform loops.

IV.—The Work of Professor Lacroix on the Laterites of French Guinea.

By L. Leigh Fermor, D.Sc., A.R.S.M., F.G.S., Geological Survey of India.

(Continued from January Number, p. 37.)

IV (*b*). *Zone of Concretion.*

In this zone the phenomenon of *départ* or *leaching* is carried to a finish, and though of little significance in the case of the gibbsitic laterites of the diabases, gabbros, and syenites, since these from the beginning of alteration in the zone of leaching have been deprived of the greater part of the elements to be removed, yet in the case of the mica-schists it is of great importance. But in every case there is an accentuation of a phenomenon already evident in the preceding zone, namely the *emigration of iron towards the surface*, where it becomes concentrated.[1] At the same time concretionary phenomena, often resulting in the separation of the hydrates of iron and aluminium one from the other, become increasingly important and reach their maximum development quite close to the surface, where they lead to the formation of a resistant crust (*cuirasse*), in which hydroxide of iron acts as cement; this hydroxide may even become sufficiently abundant to constitute an ore of iron, particularly in the case of certain diabases, and above all of peridotites.

In Professor Lacroix' opinion the formation of a continuous crust depends on definite topographical conditions (horizontal plateaux or gentle slope of the ground).[2] Thus the author regards as inadmissible the hypothesis according to which the formation of the *iron-ores* of Guinea is ascribed to the mechanical concentration of iron oxides by running water;[3] instead, in the cases described by Professor Lacroix, the hydroxide of iron has superposed itself on the pre-existing elements of the superficial crust: "il s'accumule de bas en haut."

Corresponding to the three modes of alteration in the zone of leaching, resulting, respectively, in the formation of gibbsitic laterites, ferruginous laterites, and kaolins and lateritic clays, Professor Lacroix finds three types of end-products resulting from the completion of the process of lateritization in the zone of concretion. These are gibbsitic, ferruginous, and bauxitic types, respectively, of which the latter type in particular tends to be pisolitic.

Gibbsitic Types.—The readiness with which iron oxide takes part in concretionary changes is manifest to the eye, but the mobility of

[1] Lacroix notices that this ascension of iron towards the surface was observed long ago by Hislop (1857, Lacroix gives 1863), and later by Maclaren (1906), in the laterite of India, and by Arsandaux in that of Western Africa and of the Congo, and by many other authors.

[2] While this is doubtless true from the point of view of the actual result, Professor Lacroix overlooks the circumstance that on steep slopes the products of weathering are rapidly removed by erosion, so that lateritic products have no chance of accumulating.

[3] Lacroix remarks that this theory has already been proposed by Holland (Geol. Mag., 1903, p. 62) to explain the formation of the low-level laterites of India, to which Holland attributes a detrital origin. Lacroix does not, however, regard the two cases as comparable.

TABLE I.—ANALYSES OF LATERITES DERIVED FROM NEPHELINE-SYENITES.

Original Rocks.	Nepheline-syenites.			
Locality.	Kassa I.	Roume I.	Kassa I.	Fotabar.
Position in Section.	Fresh rock.	Zone of leaching.	Zone of concretion.	Zone of leaching.
Name of Rock.	Nepheline-syenite.	Porous gibbsitic laterite.	Compact gibbsitic laterite.	Clay (gibbsitic).
Number.	1	2	3	4
SiO_2	56·88	2·21	0·37	35·14
TiO_2	0·29	0·12	0·90	0·70
Al_2O_3	22·60	55·83	57·12	40·08
Cr_2O_3	—	—	—	—
Fe_2O_3	0·97	5·22	7·41	4·12
FeO	2·19	—	—	—
CaO	1·33	0·24	0·17	0·45
MgO	0·56	0·19	—	0·21
Na_2O	8·30	0·49	0·26	—
K_2O	5·57	0·27	0·37	—
P_2O_5	0·08	—	—	—
H_2O	0·98	30·47	33·71	17·84
Insoluble	0·34(Cl)	5·74	0·30	1·46
	100·09	100·78	100·61	100·00
Mineral Composition :—				
$Al_2O_3 . 2SiO_2 . n H_2O$ (clay) [1]	—	5·0 (3)	0·8 (2)	76·6 ($2\frac{1}{5}$)
$Al_2O_3 . 3H_2O$ (gibbsite)	—	82·5	86·9	15·6
$Al_2O_3 . H_2O$ (colloidal)	—	—	—	—
$2Fe_2O_3 . 3H_2O$ (limonite and stilpnosiderite)	—	6·1	8·6	4·8
Hematite	—	—	—	—
$TiO_2 . H_2O$	—	0·1	1·1	0·8
Insolubles	—	5·7	0·3	1·5
	—	99·4	97·7 [2]	99·3 [3]

Notes.—The mineral compositions have been recalculated by me, because Lacroix takes no account of the insolubles or titania, and often omits to state the composition of the *argile*.

[1] The value of n is shown in brackets in each case, n being 2 per kaolinite.

[2] Omitting a surplus of 2·08 % water above that required per $n=2$ in the silicate. It is equivalent to 37 H_2O if taken into the silicate.

[3] Lacroix terms this rock *argile bauxitique*, but describes the presence of gibbsite.

DIABASES, AND PERIDOTITES.

Diabases and Gabbros.			Peridotites.		
Mt. Bougourou.			Mt. Kakoulima.	Railway, km. 10.	?
Fresh rock.	Zone of leaching.	Zone of concretion (cuirass).	Fresh rock.	Zone of leaching.	Zone of concretion (cuirass).
Diabase.	Porous argillaceous (*silicatée*) gibbsitic laterite.	Compact gibbsitic laterite.	Peridotite.	Porous argillaceous ferruginous laterite.	Ferruginous laterite[6] (iron-ore).
5	6	7	8	9	10
51·27	5·83	1·30	38·32	12·67	—
0·70	1·29	1·03	0·28	0·55	—
12·36	37·03	60·19	2·66	12·59	4·80
—	—	—	0·16	—	0·20
3·29	31·73	3·91	4·35	46·84	83·50
6·16	—	—	11·78	—	—
10·66	0·19	0·17	2·74	0·04	—
13·26	0·06	—	36·22	1·26	—
1·60	—	—	0·16	—	—
0·41	—	—	0·06	—	—
0·11	—	—	—	—	—
0·40	23·02	32·00	3·38	15·32	10·18
—	0·96	1·40	—	10·73[5]	1·70[5]
100·22	100·11	100·00	100·11	100·00	100·38
—	12·5 (2)	2·8 (2)	—	30·1 ($3\frac{1}{2}$)	—
—	43·2[4]	87·9	—	2·9	7·3
—	4·5	1·9	—	—	—
—	37·1	4·6	—	54·7	52·9
—	—	—	—	—	38·3
—	1·6	1·3	—	—	—
—	1·0	1·4	—	10·7	1·7
—	99·9	99·9	—	98·4	100·2

[4] Lacroix regards all the Al_2O_3 as present as gibbsite, presumably assigning to the *argile* a lower state of hydration than $n=2$.

[5] Picotite.

[6] Sample obtained by powdering twenty-five pieces of red ore.

the alumina, although less apparent, is none the less real, as Professor Lacroix demonstrates by means of chemical analysis (compare analyses Nos. 3, 7, 10 with Nos. 2, 6, 9, see Table I), and has followed in detail under the microscope; little by little the ferruginous products, which, in the diabases and syenites, occupy the places of the heavy silicates, are replaced by gibbsite, which, in addition, fills in all the spaces in the rock. This mineral must be regarded, therefore, as rather soluble in the underground waters, as is obvious when one recalls cases of crystalline gibbsite in geodes and cracks in laterites and ores from Guinea, India, Brazil, and New Caledonia. The final result of the transport and recrystallization of gibbsite is the formation of *granular crystalline rocks* of relatively coarse grain composed almost entirely *of gibbsite.*

Ferruginous Types.—In the case of laterites derived from peridotites the zone of concretion, owing to the poverty of the original rock in alumina, corresponds with the ferruginous crust. This crust shows every variety of concretionary form of *limonite* and *stilpnosiderite*; and at the actual surface the limonite becomes more or less dehydrated with appearance of red tints, indicating doubtless the formation of *hematite* (see analysis No. 10, Table I, p. 79).

Bauxitic Types.—In contrast to the zone of concretion of the laterites derived from diabases and syenites, the characteristic of the zone of concretion capping the kaolins and lateritic clays of the zone of leaching of the mica-schists, granites, and gneisses, is that *the aluminium hydrate*, which, little by little, replaces the aluminous silicate, *assumes at first the colloidal form* (see analyses Nos. 11, 12, 13, Table II). Although, in this case, gibbsite is often present, it is always accompanied by an important and often predominant proportion of colloidal hydrates, and Professor Lacroix maintains that this crystalline mineral is a product of transformation of the colloidal forms; and by means of the evidence of thin sections he proves his contention in the case of the pisolitic laterites.

Pisolitic Laterites.—Speaking generally, one of the characteristics of the crust or cuirass is the abundance of pisolitic forms. It has long been held that pisolites in general have been formed in waters in movement, and recently this idea has been used to explain the formation of the pisolitic bauxites of Arkansas. But although Professor Lacroix admits the legitimacy of such an opinion in the case of the siliceous or calcareous pisolites of thermal springs, he regards it as indefensible in the case of laterite. On the contrary, the pisolites of laterite, like those found in clays formed by the decalcification of limestone, have been formed *in situ* in a medium in a state of rest, and in general have not suffered transport since their formation; their form, degree of regularity, and size depend on the physical state of this medium. The best condition for the formation of pisolites is, according to Lacroix, the existence of a homogeneous medium, enclosing few or no solid elements insusceptible of concretionary re-arrangement, unless in small grains; this explains the abundance of pisolites in the lateritic crusts of mica-schists, clays, and alluvium.

Professor Lacroix here (p. 342) refers to the section of my

classification of laterites instituted for *lake laterites*, a name suggested for any of the pisolitic laterites that can be proved to have been formed by deposition from solution in bodies of water on the analogy of the Swedish lake ores of iron. Professor Lacroix has not seen personally in Guinea any pisolitic rocks, formed necessarily by a process of this nature, and remarks that the conditions realized in the temporary pools of water on the surface of the *bowals*[1] are sufficient to explain all the facts observed. It should be noted that I did not suggest that pisolitic laterites in general would prove to be lake laterites, but proposed this division to allow for eventualities, suggesting only that two particular cases of pisolitic limonite might prove to belong to this division. In view of Lacroix' account of the pisolitic laterites of Guinea, I am quite prepared for the future to show that true lake laterites are a very rare type. Obviously, however, there must be some relationship between laterites deposited chemically in lakes, and those formed in small pools on the surface of already existing laterites.

Continuing, Professor Lacroix remarks that ferruginous pisolites are found in the cuirass of all the lateritic types, colloidal hydroxide of iron being a ubiquitous product; but the same is not the case for very aluminous pisolites. In Guinea they are not found in the lateritic cuirass of the nepheline-syenites, and they are rare in that of the basic rocks; but on the contrary they are common in the cuirass of the mica-schists, granites, and clays, not only on account of the conditions of the medium already referred to, but also for another reason.

In the gibbsitic laterites the aluminous hydrosol circulates in the zone of concretion in contact with gibbsite formed from the commencement of alteration and disseminated everywhere, and the crystals of this mineral serve as nuclei, determining an almost complete crystallization. But, in the alteration of mica-schists, the whole of the alumina is liberated from its silicated compounds in the form of a gel, and exists in part in this condition in the cuirass; it can thus easily rearrange itself into pisolites, as long as crystallization has not set in. Whenever, as at Fatova and Siguiri, gibbsite is seen in these pisolites, the irregularity of its disposition, and the absence of regular fibro-lamellar structure starting from a centre, leave no doubt as to its secondary origin.

Judging from the examples given in this memoir, it might be thought that the persistence of the colloidal state bore some relation to the composition of the aluminium hydrate, the hydrate with one molecule appearing to be abundant in the bauxitic laterites, and that with three molecules in the laterites formed from the diabases and syenites. The crystallization of gibbsite in the pisolites would then be, as M. Arsandaux thinks, the result of hydration.[2] But the

[1] Name in the Foula language (p. 273) for vast horizontal or undulating tracts in Guinea, either quite bare, or covered with a meagre vegetation of grasses, *Cyperus*, and semi-aquatic plants.

[2] Lacroix notes that Maclaren (GEOL. MAG., 1906, p. 546) supposes that in India gibbsite results from hydration, contrarily to the opinion of Holland, who regards laterite as characterized by a dehydration (GEOL. MAG., 1903, p. 65). Judging from Lacroix' researches it will be seen that there is probably little

existence in Arkansas[1] and elsewhere of pisolitic laterites formed entirely of aluminium hydrate with three molecules of water, largely in the colloidal state, and only crystallized in cracks, shows that if this cause can be admitted in certain cases, it is not the general rule.

The Hardening of Laterites.—This is regarded as a non-essential property of laterite, due to the evaporation on exposure to the air of the quarry water contained in the colloidal hydroxides and silicates, and particularly in the hydroxide of iron.[2] It is only seen in those laterites containing these products in abundance, and is absent from the gibbsitic laterites derived from the diabases and syenites.

(To be concluded in the March Number.)

REVIEWS.

I.—College Physiography. By R. S. Tarr; edited by L. Martin. pp. xxii + 836, with 10 coloured maps and 503 text-figures. New York: Macmillan, 1914. Price 15*s*.

THE late Professor R. S. Tarr was well known in this country as one of the ablest exponents of the modern American school of physical geography. Besides publishing during his lifetime several small textbooks of physiography, he projected a large and comprehensive work on the same subject. At the time of his death in 1912 some twenty chapters of the book were written; after consultation with Mrs. Tarr and some leading American geographers, Professor Lawrence Martin, of the University of Wisconsin, undertook to supply the remaining chapters and to edit the whole work. The result is a book of over 800 pages, with some 500 illustrations. As stated in the editor's preface, it is intended "for use in elementary physical geography courses in universities, colleges, and normal schools, for supplementary reference-reading by high-school students who are using a more elementary text, and for general reading by laymen of mature years". The first reflection that suggested itself to the reviewer is that American college students cannot be in the habit of doing their serious reading in arm-chairs, such a proceeding in this instance being barred by the enormous weight of the book, which scales nearly 4 lb. avoirdupois.

change in the state of hydration of the oxides of aluminium and iron once they have been deposited, except in the cuirass, where the limonite and stilpnosiderite tend to lose their water with formation of hematite, whilst the aluminium hydrates are unaffected.

[1] Lacroix was able to visit the bauxite deposits near Little Rock last summer, and concludes that they must be regarded as laterites formed from alkaline-syenites, with kaolin characterizing the zone of leaching and bauxite the zone of concretion.

[2] It is interesting to recall here Holland's suggestion that the loss of water accompanying the hardening of laterite is due to the crystalline affinity of Fe_2O_3 in two molecules of limonite leading to the formation of crystalline hematite with rejection of water.

The original twenty chapters written by Professor Tarr deal with the lands and the oceans, while Professor Martin is responsible for one chapter on the ocean and for the whole section dealing with atmospheric phenomena. The bias of the book is certainly towards the geographical and geological side, since out of 814 pages of text 636 pages are devoted to the lithosphere. As would naturally be expected, the treatment is distinctively American; the great majority of the illustrations (of which, by the way, no list is given) are taken from that continent, though other parts of the world, when illustrating special points, are by no means neglected. In a book of this size and comprehensiveness it is difficult and perhaps invidious to single out special portions for criticism, but it may be mentioned that the sections dealing with glaciation in all its forms are particularly good, and will be read with interest by geologists and geographers on this side of the Atlantic. The very detailed study of the glaciation of the United States and Canada carried out in recent years must eventually have an important influence on the final settlement of that much-debated and still unsolved problem, the nature of the Pleistocene glaciation of the British Isles and especially of Eastern and Central England.

A chapter of great general interest deals with the relief features of the earth's surface, and this is illustrated by an excellent series of photographs of relief-models of the continents; the model of North America, for example, will serve to bring before the student in the clearest manner the threefold division of that continent—the mountain areas in the east and west and the central plain. The picture of the model of Eurasia, however, is much less successful, as it shows Europe only as a minor appendage in a lop-sided position in the north-western corner, and the scale is too small to be of much service.

Perhaps the least satisfactory portion of the book is that dealing with mountains, and especially the sections describing the mountain systems of Europe. The author's ideas as to the relative ages and mutual relations of the fold-systems of Western Europe are by no means clear, as shown by the following sentence (p. 535): "The low Urals extend north and south along the eastern boundary of Russia, and an ancient mountain range extends from northern Scandinavia through the British Isles to Brittany in France." The second clause gives no clear picture of the relations in time and space of these systems, and certainly does not give an impression of several sets of folds, of very different ages, intersecting at acute angles, as is actually the case. Fig. 340, which is somewhat vaguely labelled "The Alps in Austria, rising above the snow-line", apparently a view of Innsbrück, is scarcely calculated to impart to the intelligent but untravelled American an adequate idea of the general appearance of a European mountain range. On the other hand, many of the pictures are very good, taking into account their small size and the fact that they are printed as text-figures. The coloured plates are all well-chosen examples of the beautiful contour-maps issued by the United States Geological Survey, and to each chapter is appended an admirable bibliography.

R. H. R.

II.—Canada Department of Mines, Geological Survey; Museum Bulletin No. 3, Geological Series No. 19. The Anticosti Island faunas. By W. H. Twenhofel. 35 pp. and i pl. 30 October, 1914.

Bulletin No. 4, Geological Series No. 20. The Crowsnest volcanics. By J. D. MacKenzie. 37 pp. i pl. numbered as p. 37. 19 November, 1914.

Bulletin No. 5, Geological Series No. 21. A *Beatricea*-like organism from the Middle Ordovician. By Percy E. Raymond. 19 pp. pls. i–iv numbered as pp. 13–19. 23 November, 1914.

E. BILLINGS' "Catalogues of the Silurian Fossils of the Island of Anticosti" were issued in November, 1866, and assumed considerable importance in the history of North American Palæozoic palæontology from the number of species therein described. It was high time therefore for a renewed study of these beds and for their correlation with the numerous divisions that have subsequently been recognised both in North America and elsewhere. Dr. Twenhofel's paper is preliminary to a memoir that will ultimately be issued by the Geological Survey of Canada, and states his conclusions as follows: (1) "Billings' statement that the section is complete from base to summit and contains no stratigraphic break [although Billings admits a palæontological break] is sustained." (2) [As a result presumably of this completeness], "many of the species have ranges through greater thicknesses than the same species have in other regions." (3) There is a great difference between the faunas of the north and south shores of the island, corresponding to lithologic differences and hence to original differences of environment. (4) On the north the rocks are shaly and sandy, on the south they contain more corals and are more calcareous but not so thick.

The various series and formation names are taken from a previous paper by Schuchert and Twenhofel (1910) and are correlated as follows:—

System.	Series.	Formation.	N. America.	Britain.	Norway, etc.
Silurian.	Anticosti.	Chicotte.	Irondequoit. Rochester.	Wenlock.	Etage 8.
,,	,,	Jupiter River.	Clinton.	Upper Llandovery.	Etage 7.
,,	,,	Gun River.	Cataract and Brassfield.	Lower Llandovery.	Etage 6.
,,	,,	Becsie River.	Alexandrian.		
Ordovician.	Gamachian.	Ellis Bay.	No equivalent.	Upper Bala.	Etage 5.
,,	Richmond.	Charleton.	Richmondian of the interior.	Middle Bala.	Borkholm.
,,	,,	English Head.			
,,	Utica.	Macasty Shale.			

The following new generic and subgeneric names are proposed: *Palæofavosites*, n.g. of Favositidæ; *Strophoprian* or *Strophoprion*, n. s-g. of *Strophonella* (?, the genus is not stated); *Virgiana*, n.g. of

Pentamerana; *Protozeuga*, n.g. of Terebratuloids, with genotype *Waldheimia mawi* Davidson; *Lissatrypa*, n.g. of Atrypidæ with genotype *L. atheroidea* = *Athyris lara* Davidson non Billings.

The Crowsnest volcanics, so named from the Crowsnest Pass in Alberta, near which they occur, consist of tuffs, agglomerates, and a few flow rocks. Their interest lies mainly in the fragments of which they are composed. These, according to Mr. MacKenzie, are in order of abundance, trachytes, blairmorites, and latites. The trachytes are rich in soda and comprise varieties bearing ægirite-augite and melanite. Blairmorites, of which the name was suggested by C. W. Knight, are ultra-alkaline, soda-rich porphyries, containing phenocrysts of analcite in quantities up to 71 per cent. This occurrence links up the alkaline rocks of Montana with the ultra-alkaline intrusive mass of Ice River, B.C., so that the series form a related group "the Rocky Mountain Petrographic Province".

Anything that throws light on the problematic *Beatricea* is welcome, and Dr. Raymond's careful description of his new genus *Cryptophragmus* is illustrated by some excellent photographs. He follows Nicholson and Professor Parks in referring the Beatriceidæ to the Stromatoporoids, and regards the inner septate tube as an axial support secreted by the zooids of the ensheathing colony.

Certain remarks as to dates of publication contained in our review of the last part of this Bulletin (Geol. Mag., November 1914, p. 525) appear to have been not altogether justified. We have in consequence been favoured with a set of the papers contained in that part, each in a dated wrapper of its own and with separate pagination—a fact to which attention has been conscientiously drawn by a rubber stamp. We are therefore bound to suppose that the separate papers were actually available on those dates. This of course leaves us still wondering why it should have taken two months and a half for a copy of the whole to reach London. Bulletin No. 3 took one month and a half, and Bulletins 4 and 5 a little over a month. The war is really not enough to account for this. We are, however, very glad to see that each paper is now issued as a separate number of the Bulletin, so that there need in future be no confusion regarding either date or pagination, and it should be quite possible to publish each part on the actual date given. We cannot conclude these slightly critical remarks without recognising the generous freedom with which the Canadian authorities distribute these valuable publications, a liberality so great that no price is marked either on the works themselves or on the announcements which invite those interested to make application for them to the Director of the Geological Survey.

F. A. B.

III.—Engineering Geology. By Heinrich Ries and Thomas L. Watson. pp xxvi + 672, with 225 illustrations in the text and 104 plates. New York, John Wiley and Sons, Inc.; London, Chapman & Hall, Ltd., 1914. Price $4.00 net.

THIS treatise embodies the courses of teaching given by the authors to the students at the Universities of Connell and Virginia respectively. It affords a comprehensive survey of the

principles of geological science, and a careful study of it will enable the engineering student to face with confidence the many problems, so varied in character, that he may encounter in the course of his professional career. The scope of the book is wide, and covers such diverse subjects as the character of rocks in respect of their use for building purposes or for road-making, the structure of rocks so far as it may affect tunnelling operations and building dams or reservoirs, the conditions which determine the flow of underground waters, the character of soils in connexion with the disposal of sewage and the purification of water, the ingredients of cements and clays, the sources of coal and oil, and the nature of ore deposits. The value of the book to the engineering student is enhanced by the fact that the discussion always follows strictly practical lines; instances, mostly drawn from American occurrences, illustrating the point in question being described. The ample illustrations are well chosen and excellent in character, and the bibliography of American literature at the close of each chapter enables the reader to prosecute his study further if he so desires. The volume is, in fact, one that should find a place on the shelves of every civil engineer.

In the early chapters a brief survey is given of such parts of mineralogy and petrology as are immediately related to the subject. The necessary brevity has entailed some looseness in expression; it may, for instance, be questioned whether the definition of a mineral as "any natural inorganic substance of definite chemical composition", or of a crystal as "a solid bounded by flat and somewhat smooth surfaces, called faces, symmetrically grouped about imaginary lines as axes", be logically satisfactory. In the discussion of the physical characters of minerals it is pointed out that the colour may be natural, i.e. bound up with the essential composition, or exotic, i.e. due to the presence of some foreign pigment, and the authors say in the case of iron that "according to the amount present the mineral will ordinarily exhibit some shade of green, brown, or even black", but do not mention the difference of tint depending upon the state of oxidation of the iron. The characters of the principal rock-forming minerals are described in the order—silicates (the largest group), oxides, carbonates, sulphates, phosphates, and sulphides. The discussion being based upon the microscopic appearance, little is said about the optical properties. The second and third chapters deal with the general characters of rocks, divided into the customary groups—igneous, sedimentary, and metamorphic—and their structure and metamorphism The authors then pass on to the weathering of rocks and the soils resulting therefrom, the surface and underground waters, landslides, wave action, lakes, and glacial deposits. In a subsequent chapter the different kinds of building stones in use are fully treated, and their capacity to withstand the disintegrating effects of weathering, mechanical stress, and extreme heat is discussed in considerable detail. It is pointed out that the quarrymen, and we might add the general public, use the term granite in a far wider sense than is now usual in science. The properties of limes and cements, and the rocks used in road making are described, and the concluding chapter is taken up with the important subject of ore deposits. Maps showing the

distribution of the particular rocks under discussion are plentifully supplied, and reference to the volume is immensely simplified by means of excellent subject and locality indices.

IV.—Limits of the Secondary and Tertiary Periods.

In a recent number of the Proceedings of the Palæontological Society of America (Bulletin Geological Society of America, vol. xxv, p. 321, 1914) Professor H. F. Osborn gives an interesting summary of a discussion held at a meeting of the Society as to the precise line that should be drawn between the Secondary and Tertiary periods. Very divergent views seem to have been expressed. Thus Dr. F. H. Knowlton endeavoured to show that palæobotany indicates that no sharp line of demarcation exists between the two periods, and expressed his belief that the real division occurred long before the close of the Age of Reptiles. On the other hand, most of the disputants seem to have tended to the traditional view that the extinction of the Dinosaurs marks the termination of the Cretaceous period and that the only important survival of a Cretaceous reptile till Tertiary times is that of *Champsosaurus*. Several papers resulting from this discussion have been published in the Proceedings of the Geological Society of America, especially by W. D. Matthew ("Evidence of the Palæocene Vertebrate Fauna on the Cretaceous–Tertiary Problem") and Barnum Brown ("Cretaceous–Eocene Correlation in New Mexico, Wyoming, Montana, Alberta"). Dr. W. J. Sinclair has also contributed an important paper to this discussion (Bulletin American Museum Natural History, 1914, p. 297).

V.—Brief Notices.

1. British Museum (Natural History).—The "Return" ordered by the House of Commons for 1913–14 (price 1*s.*) is as interesting as its predecessors. A systematic record of accessions to the Geological and Mineralogical Departments is given. Among the principal items are the Piltdown skull, etc.; specimens illustrating the Holocene deposits of Newquay and the North of Ireland; Trilobites from the Comley Sandstone; large collections of Carboniferous and Devonian corals; three Silurian corals figured by Thomas Pennant in 1757; 760 Carboniferous and Devonian fishes (Traquair Collection); 1,400 Carboniferous and 300 Cretaceous fossils from Ireland (Wright and Donaldson Collections); the Pennant Collection of minerals; rocks from Ecuador (Whymper Collection); a fine series illustrative of the ruby-mines of Burma; and numerous exceptionally fine mineral specimens.

2. Ealing Scientific and Microscopical Society.—A report of Dr. Smith Woodward's lecture on "Fossil Man" appears in the Report for 1913–14, and some notes on "Ancient Hanwell" by Mr. H Beasley. Although the latter deals with historic times there are points of interest in topography for those who study prehistoric conditions.

3. Norfolk and Norwich Naturalists' Society.—The only paper of interest to geologists in the Transactions of this Society (vol. ix, pt. v) is an excellent sketch of the life of Horace Bolingbroke Woodward by his friend and colleague Clement Reid, illustrated by a good portrait.

4. Norwich.—The Report of the Norwich Castle Museum for 1913 has reached us. Beyond the accession of a series of Gault fossils from Elstow, Bedfordshire, there seems nothing of importance to record in the geological collections, but the general work carried on in the Museum under Mr. Frank Leney, the curator, is most excellent, and merits the highest commendation.

5. A Norfolk Geologist.—In the Bulletin (173) of the New York State Museum are reproduced two leaves from the notebooks of Richard Cowling Taylor, the well-known Norfolk geologist, who emigrated to the United States about 1830 and followed up his researches in that country. These are printed in colours, deal with American geology, and seem to connect him with the New York State Geological Survey, a connexion apparently previously unknown.

6. Rugby.—The Report of the Rugby School Natural History Society for 1913 is not very encouraging so far as geology is concerned. It is satisfactory to learn that the re-naming and re-arrangement of local fossils in the School Museum is proceeding, but there must be new fossils to be found at Napton and a systematic search should be made.

7. Liverpool Geological Society.—The President's (C. B. Travis) address issued in the Proceedings (vol. xii, pt. i) dealt with peneplanation in the British Islands, and forms a good summary of the subject. The record of Triassic footprints is continued by H. C. Beasley and F. T. Maidwell; some curious ctenoid markings on Triassic slabs are described by Beasley as possibly equisetiform in origin; and a paper by W. T. Walker describes the Liassic outcrop near Whitchurch, Shropshire.

8. The Proceedings of the Yorkshire Geological Society for 1914 contains a valuable paper by Dr. Wheelton Hind (p. 25) commenting upon the interesting facies of the Millstone Grit fauna obtained from the Cayton Gill Beds, which has "a large number of species common to it and the *Dibunophyllum* Beds of the Carboniferous Limestone, and does not contain the *Goniatite* fauna and its associated Lamellibranchia subsequently met with in the slate beds between the different members of Millstone Grit". The North American *Prothyris elegans* also found in the Millstone Grit of Scotland and at Congleton Edge is reported by Dr. Hind as occurring in the Grit at Colsterdale.

9. Paisley Abbey.—During excavations for the foundations of the restored choir of Paisley Abbey a quantity of hazel-nuts, pieces of hazel-wood, and willow stumps with other vegetable matter, were found. These are discussed in a paper by the Rev. C. A. Hall and Duncan Smith in the Trans. Paisley Phil. Inst. for 1914, where, incidentally, a good deal of information relating to the district has been brought together.

10. Fossil Mammals from the Crimea.—In a memoir entitled *Mammifères fossiles de Sebastopol* (Mem. Comité Geologique, n.s., livr. 87. Petrograd 1914) A. Borrissiak describes a mammalian fauna of Middle Sarmatian age which in many respects is very similar to the widely distributed fauna of the Pikermi type. The most important new genus is *Achtiaria*, which is a member of the Giraffidæ and not very remote in structure from *Samotherium* and *Okapi*: the dentition and some limb-bones are described. The author also gives an account of new species of *Tragoceros* and *Aceratherium* and of a new variety of *Hipparion gracile*.

11. Indian Geological Terminology.—This is a list of terms used by writers on Indian geology, now arranged in alphabetical order by Holland & Tipper in the Memoirs of the Geological Survey of India (vol. xliii, pt. i, 1913). It is modelled on the well-known American publications of similar nature, and gives the general history of the word and the present fixation of its meaning, if that meaning has changed since the introduction of the term itself.

12. In the Memoirs of the Geological Survey of India (vol. xli, pt. ii, pp. 148–245, 1914) Dr. L. Leigh Fermor contributes an interesting account of the geology and coal resources of Korea State, Central Provinces. The geological formations represented are: 1, Deccan Trap; 2, Gondwana, (*a*) Supra-Barakars, (*b*) Barakars, (*c*) Talchirs; 3, Archæan. The geology corresponds generally with the physical division into three plateaux. The lowest, that of Patna and Khargaon, is largely composed of rocks of the Talchir formation. On it rest two outliers of the Barakar rocks, comprising the Kurasia and Koneagarh Coal-fields, and these are outliers of the second or Sanhat plateau. The third or Deogarh plateau corresponds with the Supra-Barakar rocks.

13. In the Records of the Geological Survey of India (vol. xliv, pt. i, pp. 41–51, 1914), Dr. W. A. K. Christie describes a carbonaceous aerolite which fell near Chabra, in the Native State of Tonk, Rajputana, on January 22, 1911. The Tonk meteorite, as it is called, is chiefly interesting on account of its highly carbonaceous character, the chemical analysis showing it to contain no less than 2·70 per cent of carbon; the composition of the carbonaceous matter is uncertain. Under the microscope the stone appeared as a structureless, irregularly cracked mass, and, though no chrondritic structure was apparent, it should be classed as K (coaly chrondrite) in Brezina's classification.

14. Mining Districts of the Dillon Quadrangle, Montana, and adjacent Areas. By Alexander N. Winchell. United States Geological Survey, Bulletin 574. pp. 191, with 16 figures and 8 plates. Washington, 1914.

The region carefully described in this memoir lies just south of Butte, and measures about 49 miles wide east to west and 60 miles long. Gold placer-mining dates back as far as 1852 and was wonderfully productive; by the present day the diggings have been worked out, but the life of placer-mining has been prolonged by dredging operations. At the same time the deep mines have proved

of considerable importance. The future outlook is not bright owing to the apparent exhaustion of the ore bodies, and the low prices recently ruling for silver, lead, and copper. The geological structure was largely determined by intrusion from below of the great Boulder batholith — mainly a quartz-monzonite — which seems to have penetrated important areas in Tertiary times. The igneous rocks include a wide range of types. The different mines are described in detail, and a copious index is given at the close of the memoir.

15. The Fernando Fossiliferous Sandstones.—Mr. Walter A. English's paper (University of California Publications, Bull. Dept. of Geology, November, 1914) on the Fernando group of fossiliferous sandstones and shales of Newball, California, is interesting as giving the results of an attempt to decide the age and relationship of beds which have been for a number of years indeterminate. Mr. English concludes that the beds in question are probably of basal Pliocene and Upper Pliocene or Pleistocene age respectively. He gives detailed accounts of the result of his collecting in various horizons and describes seven new species (two of Lamellibranchia and five of Gastropoda).

16. Mollusca of the Marine Miocene of California.—In the Bulletin of the Department of Geology of the University of California, vol. viii, No. 7, Mr. Bruce Martin gives descriptions of seventeen new species and varieties of Gastropoda and one of Lamellibranchia from the late Marine Neocene of California. These descriptions have been prepared in advance of a paper dealing with the correlation of the Pliocene beds of the middle and west coast of California during his recent investigation, of which Mr Martin obtained the material from which the new species are forthcoming.

REPORTS AND PROCEEDINGS.

I.—Geological Society of London.

1. *December* 16, 1914.—Dr. A. Smith Woodward, F.R.S., President, in the Chair.

A lecture was delivered by Professor W. M. Flinders Petrie, D.C.L., LL.D., F.R.S., F.B.A., on the Palæolithic Age and its Climate in Egypt.

He said that the classes of worked flints peculiar in Egypt are: (1) Irregular, with broad unregulated fractures. (2) Rounders, flaked in all directions to an edged disc. (3) Hoofs, very thick, rudely domed with an obtuse edge. (4) Lunes, with obtuse edges. (5) Crescent scrapers. Irregular flints, similar to those from St. Acheul, are found in high Nile gravels.

The regular European types occur exactly like those classed as Chellean and Acheulian. The Mousterian forms are so often found in various periods that they cannot be assigned without evidence of age. The Aurignacian survive into the early civilization. The large class of flints from the Fayum desert comprises all the Solutrean types, and also Robenhausian forms. The flakes of the early civilization (8000 to 6000 B.C.) are identical with Magdalenian.

Views of the Nile cliffs show the general nature of the country and conditions. Successive changes of level are indicated by (1) the collapse of immense drainage caverns far below present level; (2) the filling of valleys with debris up to 650 feet above the present sea-level; (3) the gouging-out of fresh drainage-lines through the filling; and (4) rolled gravels on the top of cliffs 800 feet above sea-level, since when there has been no perceptible denudation by rain. The great extent of these elevations and depressions is likely to be connected with similar movements at Gibraltar, which are believed to synchronize with the movements of glacial periods in Northern Europe. The evidence of the flint ages agrees with this connexion.

Lantern-slides were exhibited by Professor W. M. Flinders Petrie in illustration of his lecture. The photographs will be published in *Ancient Egypt* for April, 1915.

2. *January* 6, 1915.—Dr. A. Smith Woodward, F.R.S., President, in the Chair.

The following communications were read:—

1. "The Silurian Inlier of Usk (Monmouthshire)." By Charles Irving Gardiner, M.A., F.G.S.

The Usk inlier lies a few miles north of Newport (Mon.). Between the coal-fields of South Wales and the Forest of Dean the Old Red Sandstone is bent into an anticline, the axis of which runs very nearly north and south. This has been denuded away to the west of Usk, and Silurian beds have been exposed, the rocks seen being of Ludlow and Wenlock age.

In the southern part of the inlier the Silurian rocks are arranged in two anticlinal folds, the axes of which run nearly north and south and dip southwards. These folds are separated by a fault. The western one is named the Coed-y-paen Anticline, the eastern one the Llangibby Anticline. The Old Red Sandstone is believed to rest unconformably on the Ludlow Beds along much of the margin of the Coed-y-paen Anticline; and beneath the Ludlow Beds, which are about 1,300 feet thick, come 35 to 40 feet of a Wenlock Limestone, which covers Wenlock Shales; of these latter some 850 feet are seen. It is impossible to separate the Ludlow Beds into an upper and a lower series, owing to the absence of the Aymestry Limestone. They are composed mainly of sandy shales and sandstones above, and of sandy shales with layers of calcareous nodules or of calcareous bands below.

Dayia navicula is a common fossil up to 240 feet from the top of the Ludlow Shales, and *Holopella gregaria* and *H. obsoleta* occur only in the uppermost beds.

At their base the Ludlow Beds seem to pass conformably down into the Wenlock Beds, and the Wenlock Limestone is probably not at the summit of the Wenlock Shales. The Wenlock Limestone occurs either in irregular layers separated by sandy shales, or in massive beds largely made up of crinoid fragments. Corals are rare in it.

The Wenlock Shales below the limestone are divisible into an upper portion, which consists of sandy shales and sandstones, and a lower portion composed of mudstones. The Coed-y-paen Anticline has been much affected by pressure, the hard Wenlock Limestone Bed has been fractured in no fewer than twelve places, and portions of it driven in on to the soft underlying shales.

In the northern part of the area there is much alluvium and drift; consequently, although no Wenlock Limestone is now to be seen beyond the Wenlock Shales, it is possible that the limestone may occur beneath the drift, as, when last exposed, the Wenlock Shales are seen dipping north-eastwards, and beyond the drift Ludlow Beds are observed near Clytha. The Llangibby Anticline extends as far north as Cwm Dowlais, and shows Ludlow Beds resting upon Wenlock Limestone, the anticline ending against an east-and-west fault. North of Cwm Dowlais nothing but Ludlow Beds are seen between the Coed-y-paen Anticline and the Old Red Sandstone, from both of which they are faulted.

An account of the Ludlow Beds along the western and eastern sides of the inlier is given, and a large amount of evidence with regard to the ages of the rocks at numerous exposures is produced in the form of lists of fossils. The fossils have all been named by Dr. F. R. Cowper Reed, who contributes an appendix in which several new species and varieties are described in detail.

2. "Some observations on Cone-in-Cone Structure and their relation to the Origin." By Samuel Rennie Haselhurst, M.Sc., F.G.S.

In a brief review our state of knowledge is summarized, and the deductions of other investigators are analysed.

The author then outlines the phenomenon of megascopic pseudo-stromatism, and certain tectonic features which are always associated with cone-in-cone structure in areas where it is greatly developed. He points to the disadvantage accruing from many observers not having seen it in situ on a large scale, and shows how a simulation of horizontality in stratification marks what he takes to be the key to the diagnosis of this structure.

Two typical areas are described:—

(1) The St. Mary's Island–Tynemouth district of the D_5 Coal-measures of Northumberland.
(2) The Hawsker–Robin Hood's Bay–Ravenscar district of the North Riding of Yorkshire.

The specimens collected in these areas are unique, and some dozen types from other areas, including Sandown, Portmadoc, Olney, Somerton, Lyme Regis, and Merivale Park, are examined in detail with reference to—

(1) Evidence furnished by distorted fossils.
(2) Chemical composition.
(3) Geometrical similarities.
(4) Microscopic structures.

The author critically examines the accepted hypothesis that cone-in-cone structure is something essentially due to crystallization.

He describes the results of some high-pressure mimetic experiments, aided by a Royal Society grant which he now gratefully acknowledges. These experiments were designed to produce this structure, and reveal what the author believes to be many new points on the origin of concretions and cone-in-cone in particular. The experiments are new, inasmuch as the media used, namely, brittle, semi-plastic, and plastic, are enclosed in tunics of varied design, and then subjected either to a high uniform hydrostatic pressure or to a direct thrust. The results are in many ways analogous to those of Ewing, Goodman, and Daubrée, who, it is remarked, did not attempt to explain cone-in-cone structures.

The author concludes from the evidence—

(1) That cone-in-cone is not due to crystallization, but is a mechanically produced structure due to great and localized pressure.
(2) That it is closely allied to the phenomenon known as pressure solution.
(3) That cone-in-cone structure is closely associated with other rock-structures which are mutually indicative the one of the other, and also of their mode of origin.

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3. *January* 20, 1915.—Dr. A. Smith Woodward, F.R.S., President, in the Chair.

1. "The Geology of the District around Machynlleth and Llyfnant Valley." By Professor Owen Thomas Jones, M.A., D.Sc., F.G.S., and William John Pugh, B.A., of the University College of Wales, Aberystwyth.

In an introduction a brief account is given of the physical features, general succession, and structure of the area, and reference is made to the work of previous investigators, especially Walter Keeping. For the major group the classification applied in 1909 to the district around Plynlimmon and Pont Erwyd is adopted, but slight differences are introduced in the arrangement of the minor groups. The classification is as follows:—

Valentian (Silurian).	C. Ystwyth Stage.				Pale mudstones with numerous laminated grit-bands.
	B. Pont Erwyd Stage.	*b.* Derwen Group. 190 feet.	5. Zone of *Monograptus halli.*	Pale-blue and greenish mudstones, with bands of dark graptoliferous shales, and some thin green flags.	
			4. Zone of *Monograptus sedgwicki.*		
			3. Zone of *Monograptus regularis.*		
			2. Zone of *Monograptus leptotheca.*		
			1. Zone of *Mesograptus magnus.*		
		a. Cwmere Group. 334 feet.	3. *Monograptus* spp. beds.	Dark rusty weathering shales and limestones.	
			2. Zone of *Diplograptus acuminatus.*		
			1. Zone of *Glyptograptus persculptus.*	'Mottled Beds' and blue mudstones.	
Hartfell (Ordovician).	A. Plynlimmon Stage.	Ty'n-y-maen Group.	Dark mudstones, grits, and some conglomerates.		

The distribution and character of these beds are described. The 'Mottled Beds' form the base of the Silurian and rest sharply on the underlying beds, and there is evidence of complete discontinuity at this level; they have proved of great service in elucidating the structure. The *Monograptus* spp. beds contain graptolites which elsewhere pertain to the zones of *Monograptus triangulatus*, *M. cyphus*, and *M. acinaces*; but another zone, that of *M. atavus*, has not been proved, although it probably occurs. The Derwen group consists of a regular alternation of mudstones and shale-bands with graptolites, which have also proved of service in mapping. Only a small thickness of the Ystwyth stage occurs, and no subdivisions are attempted.

The rocks are sharply folded, and sometimes overfolded, towards the east. Their axes range approximately north-north-east and south-south-west; the folds in the central area pitch northwards, but north of the Dovey a southerly pitch sets in. Each large fold is composed of a number of smaller folds having parallel axes, and changing in pitch more frequently than in the larger folds. Strike-faults of considerable magnitude range nearly parallel with the folding axes, and are in all cases overthrusts towards the east.

Of greater interest are the transverse faults ranging nearly east-north-east and west-south-west. Most of these are small, but their course across the higher ground is indicated by well-defined notches in the ridges that they cross. Two of these faults, the Pennal and Llyfnant Faults, are shatter-belts. The Llyfnant Fault displaces several folding axes, and overthrusts to the east on the north side. Its vertical displacement is on an average about 300 feet, but its horizontal displacement is usually over 3,000 feet. It may therefore be called a 'tear-fault'. Both the Llyfnant and the Pennal Faults exercise some influence upon the drainage system of the area.

A brief comparison of the succession with other districts is added.

2. "The Geology of the District between Abereiddy and Abercastle (Pembrokeshire)." By Arthur Hubert Cox, M.Sc., Ph.D., F.G.S.

The district is situate north-east of the area occupied by the pre-Cambrian rocks of St. Davids, and it is bounded on its northern side by the Pembrokeshire coast. Although some parts of this district have already been the subject of geological investigation, yet the stratigraphy and structure of the greater part is now described for the first time. Abereiddy itself has been, since the time of Hicks, a type locality for the Llanvirn Beds, but observations recently made by Professor O. T. Jones showed that the sequence required reinvestigation. It has now been found that the Ordovician rocks of the district do not succeed one another in a simple upward sequence, but that they have been thrown into great folds and sometimes even overfolded. The folds have subsequently been broken by extensive strike-faulting. The limbs of the folds increase in steepness as the pre Cambrian massif is approached. This folding brings up strips of Cambrian rocks, the presence of which on the North Pembrokeshire coast was previously quite unsuspected.

There is a complete sequence of Ordovician rocks from near the base of the Arenig Series to high up in the Glenkiln Group. The lowest

Arenig rocks are a series of arenaceous strata (the Abercastle and Porth Gain Beds) which correspond to the '*Nesuretus* beds' of Ramsey Island. These strata are in faulted relationship to the Cambrian, so that the true base of the Arenig is not seen. The arenaceous beds pass upwards without break into *Tetragraptus* shales, which are in turn succeeded by the *bifidus* beds. Llanvirnian volcanic rocks are represented in one part of the district by the Llanrhian Volcanic Series, which begins high up in the zone of *Didymograptus bifidus*, and in another part by the *Murchisoni* Ash, which forms the base of the *D. Murchisoni* zone. The Llandeilo Series compares closely with that of Carmarthenshire, and does not contain any volcanic rocks as was at one time supposed.

Contemporaneous igneous rocks occur at two horizons: (1) keratophyres at a high horizon in the *Tetragraptus* shales, and (2) quartz-keratophyres (soda-rhyolites) towards the top of the *D. bifidus* beds. The intrusive rocks (diabases) belong to two types, (1) sub-ophitic quartz-diabases, and (2) ophitic diabases without quartz. Both types were intruded earlier than the main folding, and consequently earlier than the cleavage and faulting.

A great north-westerly line of disturbance—the Pwll Strodyr Fault—cuts across all other structures, and brings on entirely different groups of strata.

II.—Geologists' Association.

January 8, 1915.—George W. Young, F.G.S., F.Z.S., President, in the Chair.

The following lecture was delivered: "The Value of Graptolites to the Stratigraphical Geologist." By Miss Gertrude L. Elles, D.Sc.

The value of Graptolites as chronological indices depends upon the rapidity of their evolution and their wide distribution in space. The stages in evolution correspond to a great extent with the stratigraphical classification in common use, though at certain horizons there are characteristic 'bursts'. Detailed knowledge of the different species is in no way necessary for the recognition of the different horizons. The nature and value of a Graptolitic zone depends on the assemblage of characteristic forms.

III.—Edinburgh Geological Society.

December 16, 1914.—Dr. R. Campbell, President, in the Chair.

The following papers were read:—

1. "The Whinstone Dykes of the Great Cumbrae." By Thomas Bond Sprague, LL.D.

Dr. Sprague described the whinstone dykes of the island, and the raised beaches, which form prominent features of the topography of Cumbrae.

2. "The Breccias of Cheese Bay and Yellow Conglomerates of Weak Law." (Illustrated by lantern slides, specimens, and microscopic sections.) By T. Cuthbert Day, F.C.S.

The author describes some peculiar breccias to be found in the district of Cheese Bay, near Guilane, associated with the intrusive Monchiquite Basalt. From a study of some new exposures of these breccias, lately discovered, he concludes that they are contemporaneous with the intrusion itself, and are the results of movements of the igneous magma, constituting a final phase of the intrusion. He therefore names them "Intrusion Breccias" in order to distinguish them from breccias arising from faulting or ordinary earth movements.

The author also applies the experience gained in the study of the above breccias to the interpretation of a peculiar exposure of rock on the shore at Weak Law, near North Berwick, generally regarded as a conglomerate, and shows that this large mass of material, nearly 300 yards in length and above 50 yards across at the widest part, is in reality of an intrusive nature, and is very similar in its character to the intrusion breccias of Cheese Bay.

It is also suggested that the numerous scattered exposures of Monchiquite Basalt are really connected below the surface, and represent upper parts of a great intrusive mass or batholith rather than parts of an ordinary intrusive sill.

IV.—Liverpool Geological Society.

At a meeting of the above Society held on January 12, Mr. J. W. Dunn, F.G.S., read a paper on "Skiddaw and the Rocks of Barrowdale", in which he gave a comprehensive account of the two lower divisions of the Ordovician rocks of the Lake District. A full description was included of the Long Close Dyke in the Skiddaw slates at the south-east end of Lake Bassenthwaite, and of the contact metamorphism induced by it, which Mr. Dunn had studied in detail and compared with the larger and well-known effects of the granite intrusion. The dyke is about 12 feet wide and consists of a much decomposed mica-porphyrite or diabase. The total width of altered rock, including the dyke, is about 30 feet. The paper was well illustrated with photomicrographs and lantern slides, and a large and representative collection of Lake District rocks.

OBITUARY.

We regret to record the death of Mr. Arthur Roope Hunt, M.A. (Cantab.), F.L.S., F.G.S., which occurred at his residence, "Southwood," Torquay, on December 19, 1914, at the age of 71 years. We hope to give a notice of this well-known Devonshire geologist, who has been for the past twenty-five years a frequent contributor to the pages of the Geological Magazine.